HERSCHEL SPACE OBSERVATORY

Announcement of Opportunity for Key Programmes

SPIRE Observers' Manual

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Chapter 1. Introduction

1.1. The Observatory

The Herschel Space Observatory is the fourth cornerstone mission in ESA's science programme and will explore the sky at far infrared and sub-mm wavelengths. The 3.5 m diameter Herschel telescope will be passively cooled to 80 K. The three on-board instruments – the Heterodyne Instrument for Far Infrared (HIFI), the Photodetector Array Camera and Spectrometer (PACS) and the Spectral and Photometric Imaging Receiver (SPIRE) will perform photometry and spectroscopy observations from ~60 to ~672 μm. The operational lifetime of the mission will be at least three years and the primary scientific objective is to observe the cold and dusty universe: from the dust-enshrouded galaxies at cosmological distances down to scales of stellar formation and planetary system bodies.

1.2. Purpose and Structure of Document

The purpose of this manual is to provide relevant information about the SPIRE instrument. A general overview of the instrument and its performance is given, in order to help the astronomer to plan, prepare and execute scientific observations with SPIRE. The structure of the document is as follows: we first describe the instrument (Chapter 2) and the general scientific capabilities (Chapter 3). The available observing modes and their corresponding Astronomical Observation Templates (AOTs) are presented in Chapter 4 followed by the calibration scheme and data products (Chapter 5). A cookbook for entering observations with HSpot is contained in Chapter 6 and Chapter 7 has a description of the pipeline. The manual ends with the list of Changes to the Document (Chapter 8) and finally the list of references.

1.3. Acknowledgements

This manual is based on inputs by the SPIRE Consortium and the instrument team and it is provided by the Herschel Science Centre, edited by Sarah Leeks and Ivan Valtchanov, HSC SPIRE Instrument and Calibration Scientists.

1.4. Acronyms

AOR	Astronomical Observation Request
AOT	Astronomical Observation Template
BSM	Beam Steering Mirror
DCU	Detector Control Unit
DP	Data Processing
DPU	Digital Processing Unit
ESA	European Space Agency
FCU	FPU Control Unit
FIR	Far Infrared Radiation
FOV	Field of View
FPU	Focal Plane Unit
FTS	Fourier-Transform Spectrometer

HCSS	Herschel Common Software System
HIFI	Heterodyne Instrument for the Far Infrared
HSpot	Herschel Observation Planning Tool
IA	Interactive Analysis
ILT	Instrument Level Test (i.e. ground tests of the instrument without the spacecraft)
ISM	Inter Stellar Medium
JFET	Junction Field-Effect Transistor
NEP	Noise-Equivalent Power
OPD	Optical Path Difference
PACS	Photodetector Array Camera and Spectrometer
PAL	Product Access Layer
PCAL	Photometer Calibration Source
PFM	Proto-Flight Model of the instrument
PLW	SPIRE Photometer Long (500 µm) Wavelength Array
PMW	SPIRE Photometer Medium (350 µm) Wavelength Array
PSW	SPIRE Photometer Short (250 µm) Wavelength Array
PTC	Photometer Thermal Control Unit
RSRF	Relative Spectral Response Function
SCAL	Spectrometer Calibration Source
SED	Spectral Energy Distribution
SLW	SPIRE Long (316-672 µm) Wavelength Spectrometer Array
SMEC	Spectrometer Mechanism
SNR	Signal-to-Noise Ratio
SPG	Standard Product Generation
SPIRE	Spectral and Photometric Imaging REceiver
SSW	SPIRE Short (194-324 µm) Wavelength Spectrometer Array
ZPD	Zero Path Difference

Chapter 2. The SPIRE Instrument

2.1. Instrument Overview

SPIRE contains a three-band imaging photometer and an imaging Fourier-Transform Spectrometer (FTS), both of which use bolometer arrays operating at 0.3 K and are coupled to the telescope by hexagonally close-packed conical feedhorns. Three bolometer arrays are used for broad-band photometry ($\lambda/\Delta\lambda$ ~3) in spectral bands centred on approximately 250, 350 and 500 µm. The same 4 x 8 arcmin field of view is observed simultaneously in these three bands through the use of two fixed dichroic beam-splitters. Signal modulation can be provided either by SPIRE's two-axis Beam Steering Mirror (BSM) or by scanning the telescope across the sky. An internal thermal source is available to provide a repeatable calibration signal for the detectors (and can also be seen by the FTS detectors).

The FTS has spatially separated input and output ports. One input port views a 2.6-arcmin diameter field of view on the sky and the other is fed by an on-board reference source. Two detector arrays at the output ports cover overlapping bands of 194-324 µm and 316-672 µm. The FTS spectral resolution is set by the total optical path difference, and can be adjusted between 0.04 and 1 cm^{-1} (corresponding to $\lambda/\Delta\lambda = 1000 - 40$ at 250 µm).

The photometer and spectrometer both have cold pupil stops conjugate with the Herschel secondary mirror, which is the system pupil for the telescope and defines a 3.29 m diameter used portion of the primary. Feedhorns provide a roughly Gaussian illumination of the pupil, with an edge taper of around 8 dB in the case of the photometer arrays.

The SPIRE cold focal plane unit (FPU) is approximately 700 x 400 x 400 mm in size and is supported from the 10 K cryostat optical bench by thermally insulating mounts. The inside is divided into two compartments, on either side of a central panel. One side contains common input optics and the photometer, and the other side contains the FTS.

The FPU has three temperature stages: the Herschel cryostat provides temperatures of 4.5 K and 1.7 K via high thermal conductance straps to the instrument, and an internal ^{3}He refrigerator cools all five detector arrays to approximately 0.3 K. Two sets of JFET preamplifiers are used to read out the bolometer signals, one for the photometer and one for the spectrometer. The JFET units are attached to the 10 K optical bench next to the 4.5 K enclosure, with the JFETs heated internally to their optimum operating temperature of ~120 K.

There are three SPIRE warm electronics units: the Detector Control Unit (DCU) provides the bias and signal conditioning for the arrays and cold electronics, and demodulates and digitises the detector signals; the FPU Control Unit (FCU) controls the ^{3}He cooler and the two FPU mechanisms, and reads out all the FPU thermometers; and the Digital Processing Unit (DPU) runs the on-board software and interfaces with the spacecraft for commanding and telemetry. The 130 kbs available data rate allows all photometer or spectrometer detectors to be sampled and the data transmitted to the ground with no on-board processing.

The relative position of the SPIRE focal plane with respect to the other two instruments, HIFI and PACS, is shown in Figure 2.1.
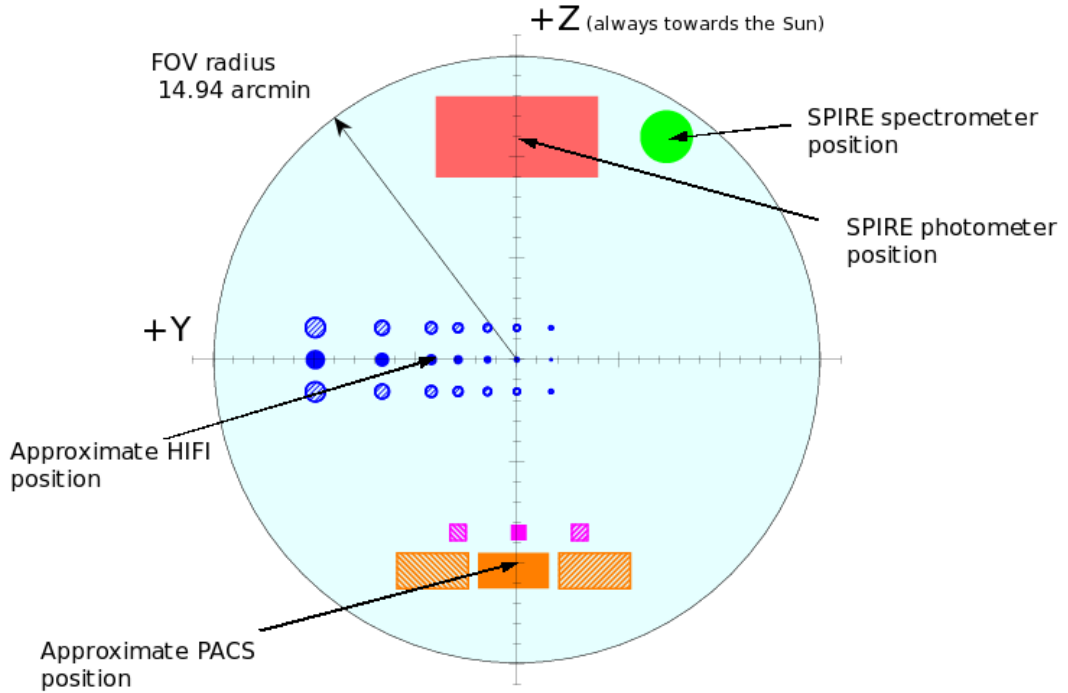
Figure 2.1. SPIRE location on sky with respect to the other two instrument sharing the Herschel focal plane. The centre of the SPIRE photometer is offset by ~11 arcmin from the centre of the highly curved focal surface of the Herschel telescope, shown by the large shaded circle.

A summary of the most important instrument characteristics is shown in Table 2.1 and the operational parts of SPIRE are presented in the subsequent sections.

Table 2.1. SPIRE overall characteristics.

Sub-instrument	Photometer			Spectrometer	
Array	**PSW**	**PMW**	**PLW**	**SSW**	**SLW**
Band (μm)	250	350	500	194-324	316-672
Resolution ($\lambda/\Delta\lambda$)	3.3	3.4	2.5	~40-1000 @ 250 μm (variable)[a]	
Unvignetted field of view	4' x 8'			2.6' (diameter)	
Beam FWHM size (arcsec)	18	25	36	16	34

[a]The unapodised spectral resolution can be low ($\Delta\sigma = 1$ cm^{-1}), medium ($\Delta\sigma = 0.25$ cm^{-1}) or high ($\Delta\sigma = 0.04$ cm^{-1}). See Chapter 4 for details.

The photometer and spectrometer parts of the instrument are described in Section 2.2 and 2.3, and some common elements (bolometer arrays, ^{3}He cooler and warm electronics) are described in Section 2.4. A more detailed description of SPIRE can be found in Griffin et al. (2006) and references therein (but it should be noted that the sensitivity estimates have since been updated with respect to the numbers given in that paper).

2.2. Photometer

2.2.1. Photometer concept, optics and layout

The photometer is implemented as a three-band camera with a single field of view common to three detector arrays. The optical scheme brings the telescope focal plane first to an intermediate pupil, at

which a Beam Steering Mirror is placed, and thence to an intermediate focal plane (at which the FTS field of view is picked off). This is in turn re-imaged by a one-to-one optical relay onto the detectors. The highly tilted and curved focal surface of the telescope is corrected by the optics so as to produce flat and undistorted focal planes at the arrays.

The layout of the common input optics and the photometer side of the instrument is shown in Figure 2.2. The input mirror M3 lies below the telescope focus, and receives the f/8.7 Herschel telescope beam and forms an image of the secondary at the flat beam steering mirror, M4. Mirror M5 converts the focal ratio to f/5 and provides an intermediate focus at M6. The three mirrors M7, M8 and M9 (inside the 1.7 K box) form an optical relay to bring the focal plane to the detector arrays. The beam is spectrally divided and directed onto the three arrays a by a combination of two fixed dichroics and flat folding mirrors (also inside the 1.7 K box). M3-M8 are at 4.5 K and all subsequent optical elements are at 1.7 K.
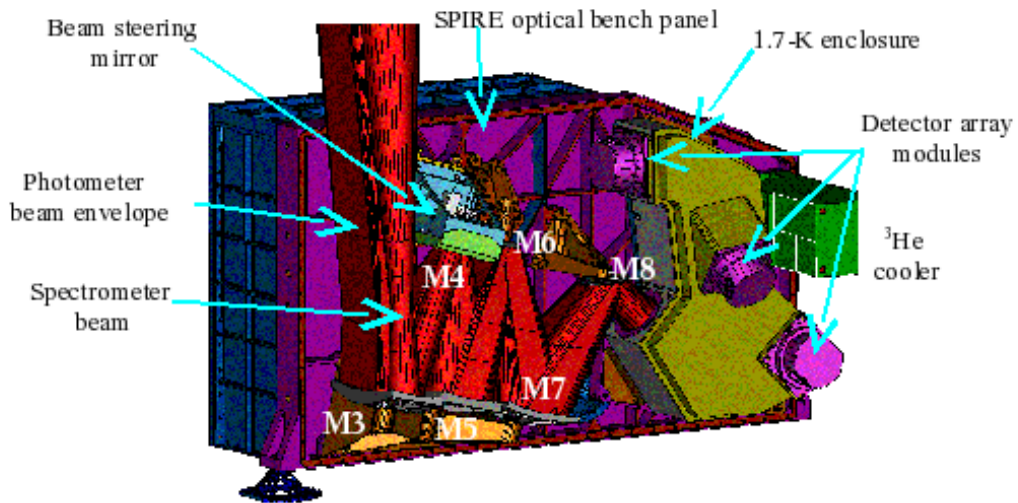
Figure 2.2. A model of the SPIRE photometer.

2.2.2. Beam Steering Mirror (BSM)

The BSM (M4 in Figure 2.2) is located in the optical path before any subdivision of the incident radiation into photometer and spectrometer optical chains, and is used both for photometer and FTS observations. For photometric observations of point sources the BSM is used to make a small map around the nominal position to eliminate pointing or source position uncertainties. For small maps using the photometer (and also the FTS), it is used to create a fully sampled image. It can chop up to ±2 arcmin along the long axis of the 4 x 8 arcmin field of view. The nominal chop frequency for the photometer is 2 Hz. It can simultaneously chop at up to 1 Hz in the orthogonal direction by up to 30". This two-axis motion allows "jiggling" of the pointing to create a fully sampled image of the sky.

2.2.3. Filters and passbands

The spectral passbands are defined by a sequence of metal mesh filters at various locations (the instrument input aperture, directly in front of the detector, and at intermediate locations in the optical train), the reflection/transmission edges of the dichroics, and the cutoff wavelengths of the feedhorn output waveguides. The three bands are centred at approximately 250, 350 and 500 μm, with $\lambda/\Delta\lambda$ of 3.3, 3.4, and 2.5 respectively. Figure 2.3 shows the overall transmission curves for the three photometer bands for typical detectors. The detailed transmission will vary somewhat across the arrays. The transmission data for all detectors will be available as calibration products (see Chapter 5). It should be noted that the overall spectral response of the instrument is not fully represented by these curves – the overall system throughput (AΩ product) also varies across the bands.

2.2.4. Photometer Calibration Source (PCAL)

PCAL is a thermal source used to provide a repeatable signal for the bolometers. It operates as an inverse bolometer – applied electrical power heats up an emitting element to a temperature of around 80 K, causing it to radiate FIR power which is seen by the detectors. It is not designed to provide an absolute calibration of the system - that will be done by observations of standard astronomical sources (see Chapter 5). It radiates through a 2.8 mm hole in the centre of the BSM (occupying an area contained within the region of the pupil obscured by the hole in the primary). Although optimised for the photometer detectors, it can also be viewed by the FTS arrays. PCAL will be operated at regular intervals in-flight in order to check the health and the responsivity of the arrays.
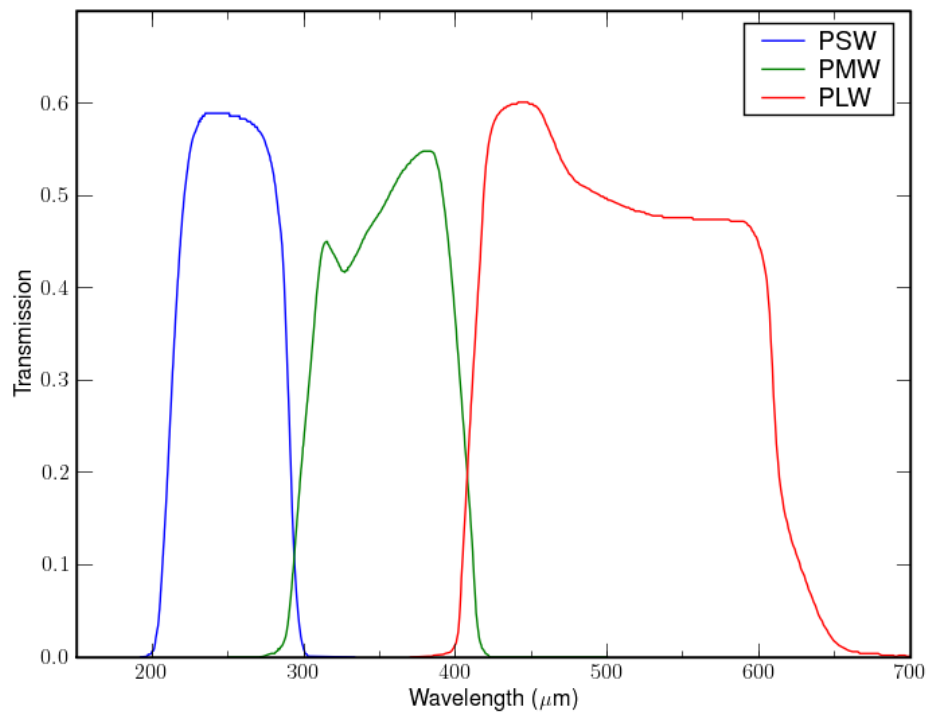
Figure 2.3. SPIRE photometer overall passbands for typical detectors.

2.2.5. Photometer Detector Arrays

The three arrays contain 139 (250 µm), 88 (350 µm) and 43 (500 µm) detectors, each with its own individual feedhorn. The array feedhorn layouts are shown schematically in Figure 2.4. The design features of the detectors and feedhorns are described in more detail in Section 2.4.
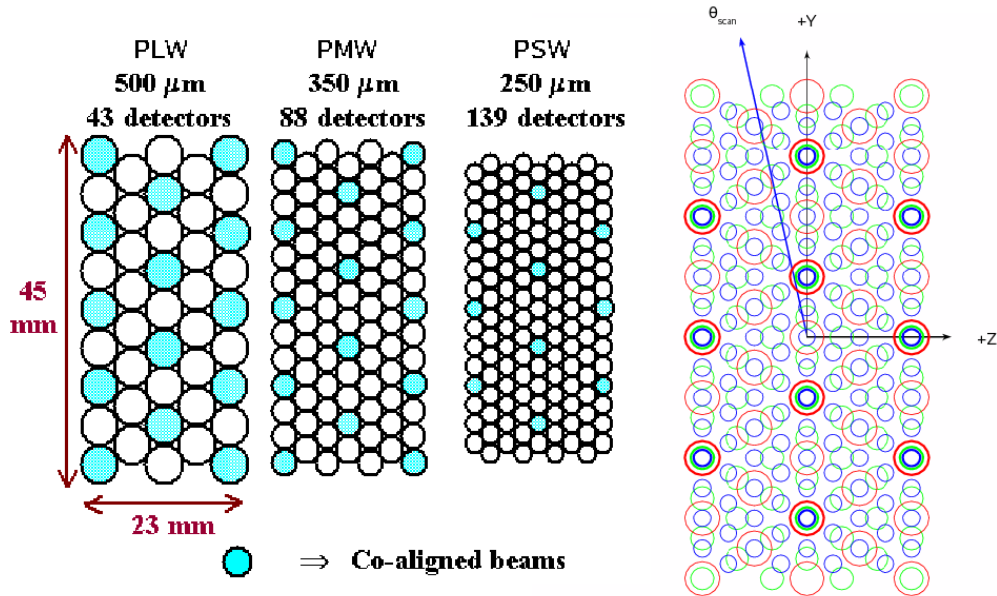
Figure 2.4. A schematic view of the photometer bolometer arrays. Each circle represents a detector feed-horn. Those detectors centred on same sky positions are shaded in the left hand side figure. The unvign-etted field of view of each array is 4x8 arcmin. The three arrays overlap on the sky as shown in the right hand side figure, where the PLW (500 μm), PMW (350 μm) and PSW (250 μm) are depicted by red, green and blue circles respectively. The circle size corresponds to the FWHM of the beam. The satellite coordinate system as well as an example of a scan direction are also shown in the right hand side figure.

2.3. Spectrometer

2.3.1. Fourier-Transform Spectrometer Concept

The SPIRE Fourier-Transform Spectrometer (FTS) uses the principle of interferometry: the incident radiation is separated by a beam splitter into two beams which travel different optical paths before recombining. By changing the Optical Path Difference (OPD) of the two beams with a moving mir-ror, an interferogram of signal versus OPD is created. This interferogram is the Fourier transform of the source spectrum. Performing the inverse Fourier transform thus produces the spectrum as a func-tion of the frequency.

2.3.2. Spectrometer Optics and Layout

FTS side of the instrument is shown in Figure 2.5. It uses two broadband intensity beam splitters in a Mach-Zehnder configuration (compared to a single beam splitter in a Michelson interferometer). There are two input ports and two output ports, all of which are independently accessible. This leads to a potential increase in efficiency from 50% to 100% in comparison with a Michelson interfero-meter. The interferogram measured by a detector at one of the output ports corresponds to the differ-ence between the two input ports - the amplitude of the interferogram central maximum is propor-tional to the difference in the radiant power between the ports. If they were of equal brightness, then a null interferogram would be recorded. In the case of SPIRE, the telescope input port always con-tains a high-brightness component – from the thermal radiation of the telescope itself. To com-pensate for this, a thermal source (SCAL) is placed at the other input port, allowing the large tele-scope background to be nulled. This greatly reduces the dynamic range requirements for the detector sampling. The spectrometer mirror mechanism (SMEC) scans the OPD and the interference signal is directed onto the two spectrometer bolometer arrays covering overlapping bands of 194-324 μm and 316-672 μm.

2.3.3. SCAL

The Spectrometer Calibrator (SCAL) is designed to provide a radiation input to the second port roughly equivalent to the dilute spectrum of the Herschel telescope. The primary requirement is to be able to null the central maximum (which does not necessarily require matching the spectral shape over the whole band). SCAL is located at the pupil image at the second input port to the FTS, and has two sources which can be used to simulate different possible emissivities of the actual telescope: 2% and 4%. The overall background that will be experienced in flight, and its spectral dependence, are not accurately known at this time. SCAL has been designed to be adjustable in terms of brightness and overall spectral shape by incorporating two thermal sources with independent temperature control. SCAL is required to be thermally stable for long periods - covering the exposure times of long spectroscopic observations.
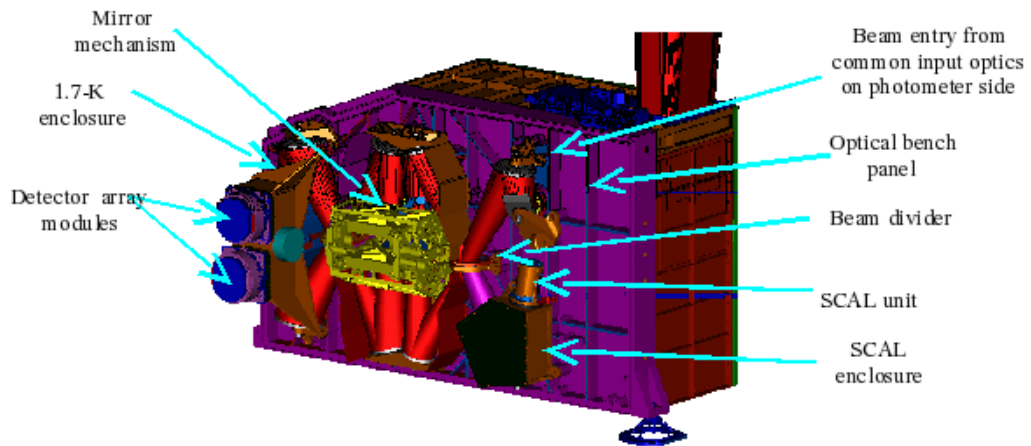
Figure 2.5. FTS layout.

2.3.4. Filters and passbands

As for the photometer, the spectral passbands are defined by a sequence of metal mesh filters at various locations and by the waveguide cut-offs. Figure 2.6 shows typical overall transmission curves for the two FTS bands. As for the photometer, there will be small variations in the shape across the arrays. The data for the transmission profiles can be accessed as calibration products (see Chapter 5). It should be noted that the overall spectral response of the instrument is not fully represented by these curves – the overall system throughput (AΩ product) also varies across the bands.
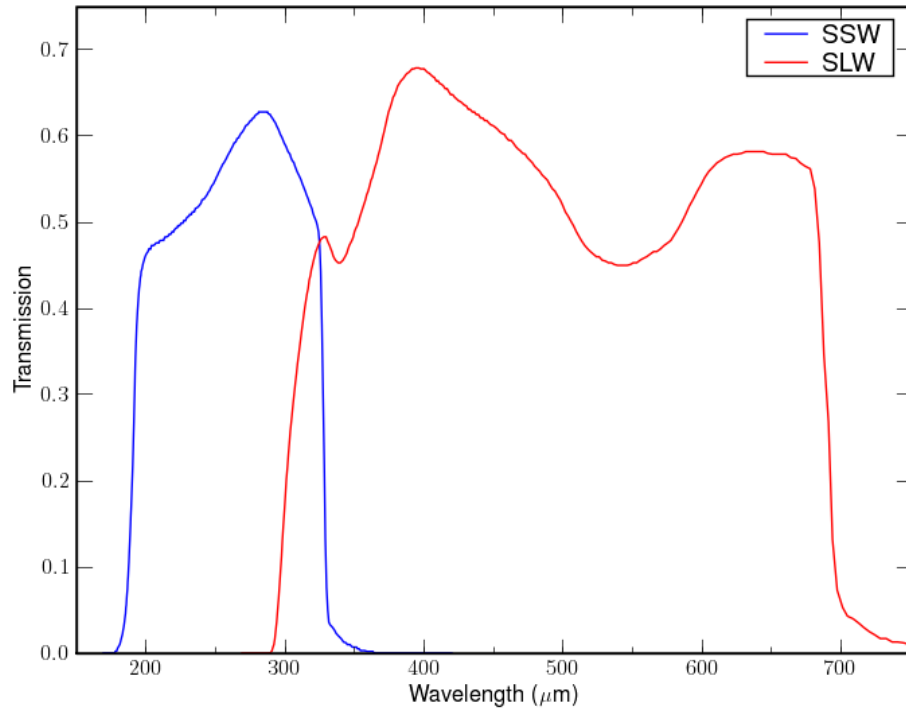
Figure 2.6. SPIRE spectrometer filter transmission curves for typical detectors.

2.3.5. Spectrometer Detector Arrays

The two spectrometer arrays contain 19 (SLW) and 37 (SSW) detectors, each with its own individual feedhorn. The arrays are hexagonally packed with a spacing between pixels of ~2 beam widths (50.5" for SLW and 32.5" for SSW). Measured pixel FWHM are ~34" for SLW and ~16" for SSW. The two arrays cover the same field of view on the sky and are designed so that most of the SLW pixels are approximately coaligned with SSW pixels. Figure 2.7 shows the overlap of the two arrays on the sky with circles representing the FWHM of the response of each pixel. The unvignetted beam footprint on the arrays (diameter 2.6') contains 7 pixels for SLW and 19 pixels for SSW. The design features of the detectors and feedhorns are described in more detail in Section 2.4.
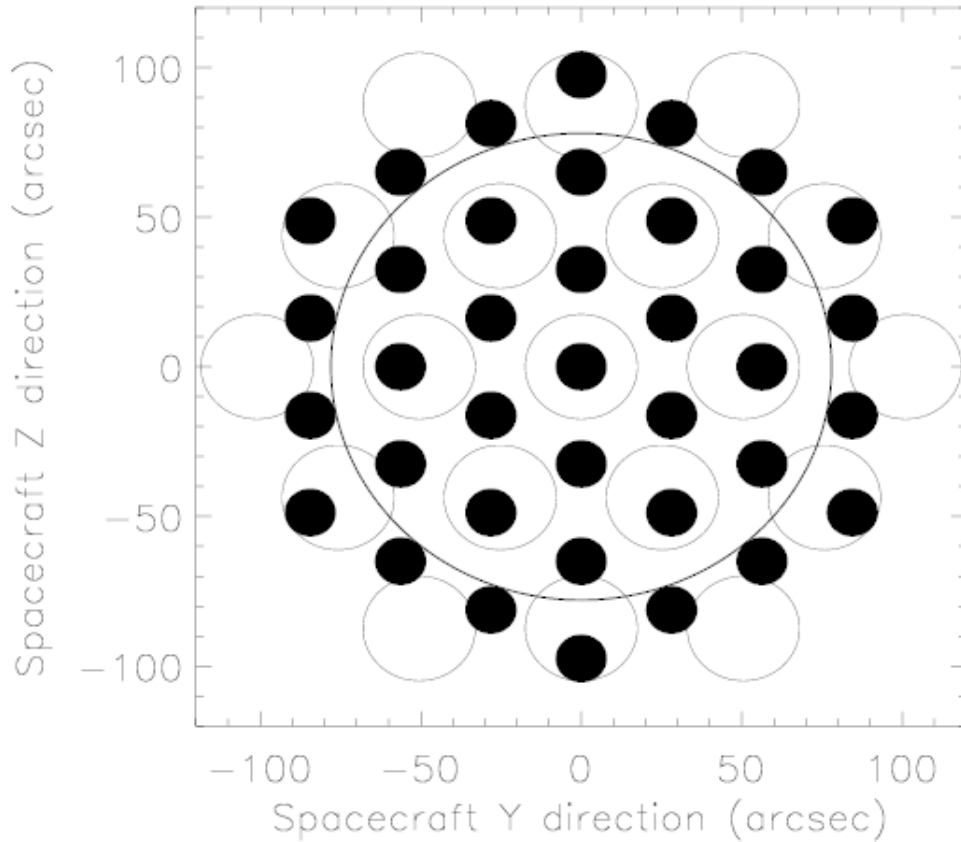
Figure 2.7. SPIRE spectrometer bolometer arrays on the sky. Filled circles are SSW (diameter 16"). Open circles are SLW (diameter 35"). The large circle shows the unvignetted beam footprint (diameter 2.6').

2.3.6. FTS spectral resolution and instrumental line shape

The nominal mode of operation involves moving the scan mirror continuously (nominally at 0.5 mm s^{-1}, giving an optical path rate of 2 mm s^{-1} due to the factor of four folding in the optics). Radiation frequencies of interest are encoded as detector output electrical frequencies in the range 3-10 Hz. The maximum scan length is 3.5 cm, equivalent to an optical path difference of 14 cm. For an FTS, the resolution element is given in wavenumbers because it is directly related to the maximum optical path difference of the scan mirror. Wavenumber σ in cm^{-1} is related to wavelength in metres by $\lambda = 1/(100*\sigma)$. For a given maximum OPD, the unapodised spectral resolution is given by $\Delta\sigma = 1/(2*OPDmax)$. The instrumental line shape is a sinc function, and using this definition of spectral resolution, $\Delta\sigma$ is the distance from the peak of the sinc function to its first zero crossing point.

The spectrometer observing modes (see Chapter 4) support three different spectral resolutions corresponding to three standard values of maximum OPD: low at $\Delta\sigma = 1$ cm^{-1}, medium at $\Delta\sigma = 0.25$ cm-1 and high resolution at $\Delta\sigma = 0.04$ cm^{-1}. The corresponding resolving power $\lambda/\Delta\lambda = \sigma/\Delta\sigma$ for the three regimes are shown in Figure 2.8. The number of independent samples in the final spectrum is set by the resolution - i.e. independent points in the spectrum are separated in wavenumber space by $\Delta\sigma$.
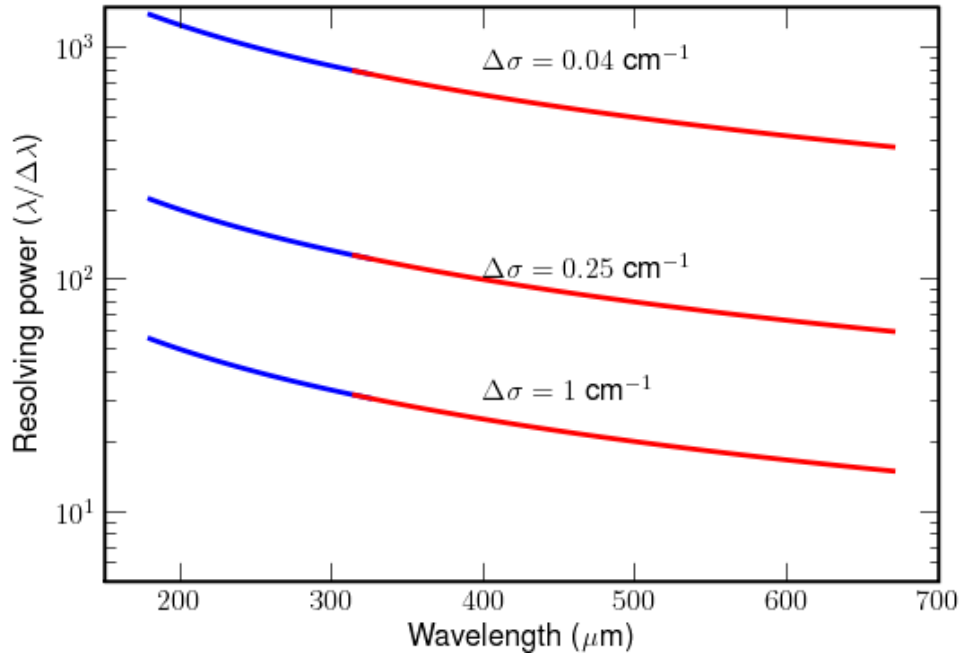
Figure 2.8. The unapodised resolving power of SPIRE FTS for three standard spectrometer resolutions (see Chapter 4). The short wavelength array SSW is shown in blue, while SLW is in red.

2.4. Common Instrument Parts

The SPIRE detectors for both the photometer and the spectrometer are semiconductor bolometers. The general theory of bolometer operation is described in Mather (1982) and Sudiwala et al. (2001), and details of the SPIRE bolometers are given in Turner et al. (2003), Rownd et al. (2003), and Chattopadhyay et al. (2003).

The basic features of a bolometer and the principles of bolometer operation are outlined here, and are illustrated in Figure 2.9. The radiant power to be detected is incident on an absorber of heat capacity C. Heat is allowed to flow from the absorber to a heat sink at a fixed temperature T_0 by a thermal conductance, G (the higher G, the more rapidly the heat leaks away). A thermometer is attached to the absorber, to sense its temperature. A bias current, I, is passed throughout the thermometer, and the corresponding voltage, V, is measured. The bias current dissipates electrical power, which heats the bolometer to a temperature, T, slightly higher than T_0. With a certain level of absorbed radiant power, Q, the absorber will be at some temperature T, dictated by the sum of the radiant and electrical power dissipation. If Q changes the absorber temperature will change accordingly, leading to a corresponding change in resistance and hence in output voltage.

Figure 2.9. Basic principles of bolometer operation.

In the case of the SPIRE detectors, the absorber is a spider-web mesh composed of silicon nitride with a thin resistive metal coating to absorb and thermalise the incident radiation. The thermometers are crystals of Neutron Transmutation Doped (NTD) germanium, which has very high temperature coefficient of resistance.

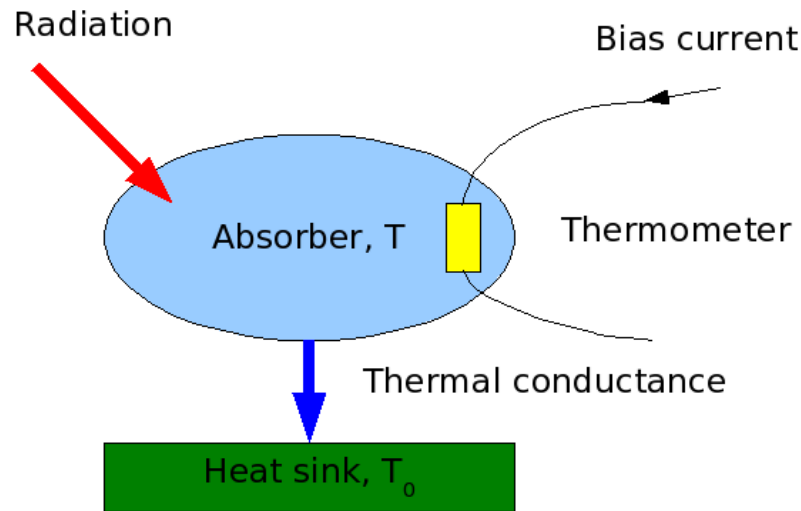The main performance parameters for a bolometric detectors are the responsivity (dV/dQ), the noise-equivalent power (NEP) and the time constant ($\tau \sim C/G$). In order to achieve high sensitivity (low NEP) and good speed of response, operation at low temperature is needed. The required sensitivity is dictated by the photon noise level arising from unavoidable statistical fluctuations in the amount of background radiation incident on the detector. In the case of SPIRE, this radiation is due to thermal emission from the telescope, and results in a photon noise limited NEP on the order of a few x 10^{-17} W Hz$^{-1/2}$. The bolometers are designed to have an overall NEP which is dominated by this contribution. To achieve this, the operating temperature for the SPIRE arrays must be of the order of 300 mK.

The operating resistance of the SPIRE bolometers is typically a few MΩ. The outputs are fed to JFETs located as close as possible to the detectors, in order to convert the high-impedance signals to a much lower impedance output capable of being connected to the next stage of amplification by a long cryoharness.

The thermometers are biased by an AC current, at a frequency in the 100-Hz region. This allows the signals to be read out at this frequency which is higher than the 1/f knee frequency of the JFETs, so that the 1/f noise performance of the system is limited by the detectors themselves, and corresponds to a knee frequency of around 100 mHz.

The detailed design of the bolometer arrays must be tailored to the background power that they will experience in flight, and to the required speed of response. The individual SPIRE photometer and spectrometer arrays have been optimised accordingly.

The bolometers are coupled to the telescope beam by conical feedhorns located directly in front of the detectors on the ^{3}He stage. Short waveguide sections at the feedhorn exit apertures lead into the detector cavities. The feedhorn entrance aperture diameter is set at 2Fλ, where λ is the design wavelength and F is the final optics focal ratio. This provides the maximum aperture efficiency and thus the best possible point source sensitivity (Griffin et al. 2003). The feedhorns are hexagonally close-packed in order to achieve the highest packing density possible. A centre-centre distance of 2Fλ in the focal plane corresponds to a beam separation on the sky of 2λ/D, where D is the telescope diameter. This is approximately twice the beam FWHM, so that the array does not produce an instantaneously fully sampled image. A suitable scanning or multiple-pointing ("jiggling") scheme is therefore needed for imaging observations.

2.4.1. [3]He Cooler and Thermal Strap System

The same [3]He cooler design (Duband 1997) is used for both the SPIRE and PACS instruments. This type of refrigerator consists of a sorption pump and a evaporator and uses porous material which absorbs or releases gas depending on its temperature. The refrigerator contains 6 litres of liquid [3]He. At the beginning of the cold phase, all of this is contained in liquid form in the evaporator. The pump is cooled to ~ 2 K, and cryo-pumps the [3]He gas, lowering its vapour pressure and so reducing the liquid temperature. The slow evaporation of the [3]He provides a very stable thermal environment at 300 mK for around 48 hours under constant heat load in normal observing and operational circumstances. Once most of the helium is evaporated and contained in the pump then the refrigerator must be recycled. This is carried out by heating of the sorption pump to ~ 40 K in order to expel the absorbed gas. The gas re-condenses as liquid at ~ 2 K in the evaporator. Once all of the [3]He has been recondensed, the pump is cooled down again and starts to cryo-pump the liquid, bringing the temperature down to 0.3 K once again. This recycling takes about 2 hours and is usually performed during the daily telecommunications period (DTCP). Gas gap heat switches control the cooler and there are no moving parts. For zero-g operation the [3]He liquid confinement in the evaporator is achieved by a porous material which holds the liquid by capillary attraction. A Kevlar wire suspension supports the cooler during launch whilst minimising the parasitic heat load. Copper straps connect the cooler 0.3 K stage to the five detector arrays, and are held rigidly at various points by Kevlar support modules. The supports at the entries to the spectrometer and photometer 1.7 K boxes are also designed to be light-tight.

2.4.2. Warm Electronics

There are three SPIRE warm electronics units. The Detector Control Unit (DCU) provides the bias and signal conditioning for the arrays and cold electronics, and demodulates and digitises the detector signals. The FPU Control Unit (FCU) controls the [3]He cooler, the Beam Steering Mechanism and the FTS scan mirror, and also reads out all the FPU thermometers. The Digital Processing Unit (DPU) runs the on-board software interfaces with the spacecraft for commanding and telemetry. The 130 kbs available data rate allows all photometer or spectrometer detectors to be sampled and the data transmitted to the ground with no on-board processing.

Chapter 3. General performance (scientific capabilities)

SPIRE is designed to exploit the particular advantages of Herschel: its large, cold, and low-emissivity telescope; its unrestricted access to the poorly explored 200-700 μm range; and the large amount of high quality observing time that will be available. These features make it well suited to key science themes: the statistics and physics of galaxy and structure formation at high redshift , and the study of the early stages of star formation. SPIRE's main science goals require capabilities of performing deep photometric imaging surveys as well as spectroscopy of individual objects at far-infrared and sub-mm wavelengths. Although the instrument design has been optimised for these two main science themes, SPIRE will also be a powerful tool for many other astrophysical studies: giant planets, comets, the galactic interstellar medium, nearby galaxies, ultraluminous infrared galaxies, and active galactic nuclei.

A significant, sometimes dominant, proportion of the total luminosity of galaxies is emitted in the FIR region, where the interstellar dust shines, heated by stellar UV radiation or accretion. The peak of the galaxy Spectral Energy Distribution (SED) of a typical star-forming galaxy falls around rest-frame wavelength of 100 μm as shown in Figure 3.1. To characterise the luminosity, dust temperature and mass, it is necessary to observe points on either side of the thermal peak. SPIRE covers the long-wavelength region for local galaxies, and the peak is redshifted into the SPIRE band for high-redshift galaxies.

In our own galaxy star formation occurs through fragmentation and collapse of dense molecular cloud cores in the interstellar medium (ISM). The early stages of this process are poorly understood and difficult to observe directly. FIR and sub-mm observations with high resolution of these pro-tostellar regions are required in order to study the bolometric luminosities and the mass function. High sensitivity, spectral coverage, and spatial resolution, and the stable observing conditions of the space observatory, will also make SPIRE ideal for studying the faint extended emission from debris disks – the ejected material around evolved stars – and thus shed light on the heavy element enrichment of the ISM.

In the solar system, SPIRE will carry out important studies of comets and asteroids, and the chemistry of the atmospheres of the giant planets Uranus and Neptune (Jupiter and Saturn are too bright to be observed by SPIRE, as is Mars).

3.1. Sensitivity

The sensitivity of SPIRE has been estimated using a detailed model of the instrument and the telescope. Some details of the model assumptions and adopted parameters are given in Griffin et al. (2002), but it should be noted that the model has since been substantially updated and modified to take in to account the results of recent instrument tests. The updated sensitivity estimates are given in this section and are used in Herschel Observation Planning Tool (HSpot, see Chapter 6 and The HSpot Users' Guide) for time estimation.

It is important to bear in mind that, as with many cryogenic infrared space instruments, predicted sensitivity figures are subject to large uncertainties (at least a factor of two) due to uncertainties in the instrument performance in flight and, in the case of SPIRE, the effective telescope background. For this reason, science programmes proposed for SPIRE should be robust against possible degraded sensitivity on the one hand, and on the other hand may be able to benefit from improved sensitivities if some of our assumptions turn out to be pessimistic. Further updates on the sensitivities will be made as our knowledge of the instrument improves through analysis of ground test data. In particular, the spectral performance and variation across the arrays will be characterised in more detail. Such refined information will be incorporated in later versions of HSpot. For the moment, the sensitivity estimates given here and in HSpot should be taken as indicative rather than definitive.
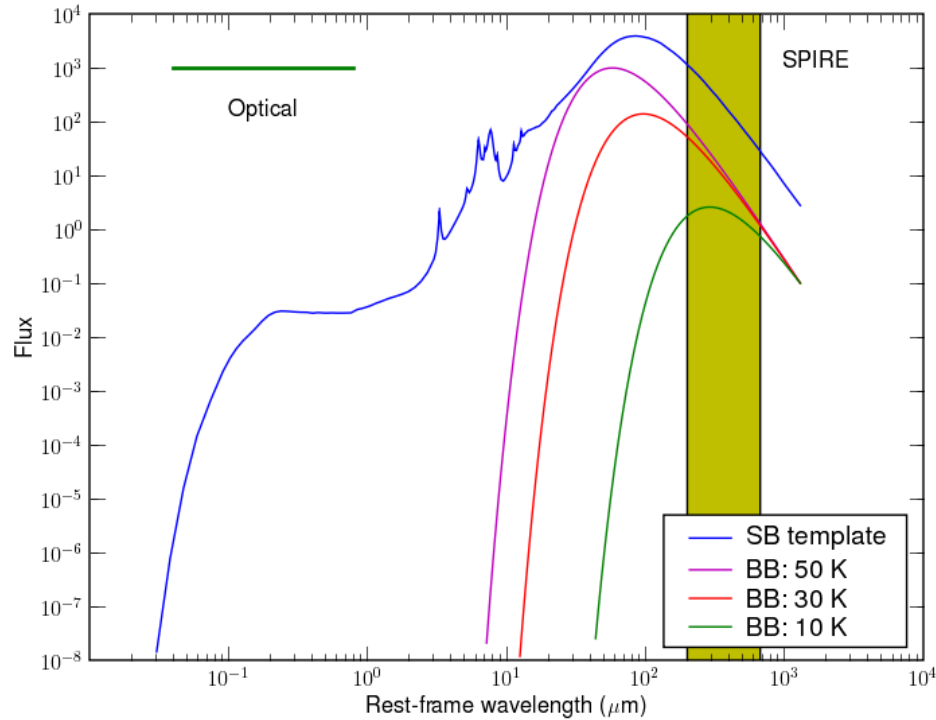
Figure 3.1. Rest-frame Spectral Energy Distribution of a star-forming galaxy and examples of a black-body spectra at three different temperatures. The wavelength range covered by SPIRE is indicated.

3.1.1. Photometer Sensitivity Estimates

The estimated SPIRE photometer sensitivities are summarised in Table 3.1. A number of important points concerning this table should be noted.

1. The values depend on the observing mode (see Chapter 4).

2. They do not include instrument or telescope overheads: they correspond to one hour of on-source integration time. The on-source integration time is the total time during which the source or region is being observed by SPIRE.

3. In some observing modes, and for short integrations, the overheads may dominate the elapsed time needed for an observation. HSpot provides observers with a full tabulation of the overheads and integration time for a given observation.

4. In Point Source Photometry mode the sensitivity assumes the ideal case in which the source is on-axis.

5. A sparse (undersampled) map of a roughly 2x4 arcmin region around the source will also be generated in this Point Source mode.

6. For mapping observations, the quoted numbers refer to detection of a point source within the map (and so include a factor taking into account the available enhancement of S/N by co-adding adjacent map pixels).

7. HSpot also tabulates surface brightness sensitivity estimates. These are simply derived from the point source sensitivities by dividing by the beam solid angle, taken to be the circular area defined by the FWHM. The factor corresponding to pixel co-addition for point source extrac-

tion is not included.

8. The field of view for Small Map mode is 4x4 arcmin rather than the total 4x8 arcmin array size. The guaranteed area is a 4 arcmin diameter circle, see Chapter 4 for details.

9. Large Maps can be made in either of two modes: cross-linked scans or single scans (see Chapter 4 for details). The sensitivity is summarised for both cases in Table 3.1, and in each case the performance is characterised in two ways: (i) the achieved point source sensitivity for one map repeat, and (ii) the on-source integration time needed to map a 1 square degree area to given sensitivity level. The on-source integration time is the total time that the arrays spend observing the requested map field, at the required constant scan speed. The number of map repeats necessary to reach this sensitivity level is also given.

The achieved sensitivities for different numbers of map repeats or on-source integration times can be scaled from these numbers. For instance, the conversion from 5 σ; 1 hr sensitivity to, say, 10 σ; 0.5 hr is as follows:

$$\Delta S(10\sigma; 0.5\,\mathrm{hr}) = \Delta S(5\sigma; 1\,\mathrm{hr}) \left[\frac{10}{5}\right] \left[\frac{1}{0.5}\right]^{1/2} = 2\sqrt{2}\Delta S(5\sigma; 1\,\mathrm{hr})$$

10. The sensitivity of scan map assumes that 1/f noise has been dealt with effectively, which is not necessarily the case for maps performed only in one scan direction. In this respect, one cross-linked scan will be better than two repeats of a single scan because of the reduction in 1/f noise.

11. Confusion noise, due to galactic cirrus and/or background infrared sources, will impose an ultimate limit on SPIRE sensitivity (see Confusion Noise Estimator for Herschel document).

12. As with most observing systems, high S/N predictions should not be taken as quantitatively correct. This is because small errors such as pointing jitter, other minor fluctuations in the system, or relative calibration errors, will then become significant. That is why a signal-to-noise of 200 is taken as the maximum achievable for any observation and for bright sources, HSpot will never return a value of S/N greater than 200.

Table 3.1. Estimated SPIRE Photometer sensitivities.

	250	350	500
Point source (7-point jiggle, 5 σ, 1 hour)	1.8 mJy	2.2 mJy	1.7 mJy
Small map (4'x4', 5 σ, 1 hour)	6.2 mJy	8.4 mJy	7.1 mJy
Large map, cross-linked scan (A+B)[a]			
5 σ sensitivity for two cross-linked scans	48 mJy	66 mJy	56 mJy
On source integration time to map 1 sq.deg. to 3 mJy 1 σ rms	8.5 hrs	16 hrs	12 hrs
Map repeats to map 1 sq.deg. to 3 mJy 1 σ rms	10	19[b]	14
Large map, single scan direction (A or B)[a]			
5 σ sensitivity for a single scan	67.5 mJy	93 mJy	79 mJy
On source integration time to map 1 sq.deg. to 3 mJy 1 σ rms	8.5 hrs	16 hrs	12 hrs
Map repeats needed to achieve 3 mJy 1 σ rms	20	38[b]	27[c]

[a]All sensitivity values are for nominal scan speed of 30"/s.
[b]The total observation duration exceeds the 18 hours limit, hence in practice the observation will have to be split into two.
[c]This is not double that of the Scan Angles A and B case because of the step nature of the observations.

3.1.2. Spectrometer Sensitivity Estimates

The predicted FTS line sensitivities (unresolved line; point source) and the point source continuum sensitivity estimates are shown in Figure 3.2 for low-resolution mode. For an FTS, the continuum sensitivity is proportional to the spectral resolution, so for medium and high resolution, the rms flux limits shown in Figure 3.2, bottom panel should be multiplied by 4 and 25, respectively.

A number of important points concerning the FTS sensitivity predictions should be noted.

1. The variation of sensitivity across the bands is indicative, and is likely to be somewhat different in practice, to vary somewhat across the arrays, and to have finer spectral structure than is shown here.

2. All FTS sensitivities are quoted for a point source on-axis; and the standard FTS data products for each pointing will be generated according to this assumption, even for map data. It will be up to the observer to combine the individual pointings to produce a fully-sampled spectral map. The reasons for this are two-fold: (i) establishing the detailed processing methods for FTS observations of extended sources will require in-flight testing and calibration; (ii) the interpretation of the data may depend on the assumed spatial structure of the source within the beam, which is not something that the data-processing pipeline can take into account. In essence, the FTS will initially be supported for point source spectroscopy. Whilst imaging observations will be possible, observers should bear in mind that the detailed analysis of the data may need some time to be perfected.

3. The line flux sensitivity for an unresolved line is in principle independent of the resolution for an FTS, so Figure 3.2 (top panel) applies to both high and medium resolution modes. In practice, it is foreseen that the performance will be better for high resolution mode, and this is recommended for sensitive line spectroscopy.

4. The FTS field of view is 2.6 arcmin diameter, but the outer ring of detectors will be partially vignetted. The unvignetted field of view is specified as 2 arcmin. Data from the full field of view will be available, but the accurate calibration of the outer parts cannot be guaranteed at this time.

5. For point source observations, a sparse map covering the full FTS field of view will also be generated.

6. As for the photometer, the maximum achievable S/N should be taken as 200.

7. Very bright sources (value TBC) will require a different detector bias settings to avoid saturation of the on-board electronics.

8. Note that the detector offsets are set *once* at the start of each observation. This means that if the source has a very large gradient in flux, the detector dynamic range may not be optimised for all jiggle points in an intermediate or fully sampled image. For example this could apply to faint emission directly surrounding very bright (relative to the signal from nulled telescope emission) point-like sources, and would lead to clipping of the signal in either the bright or faint case.
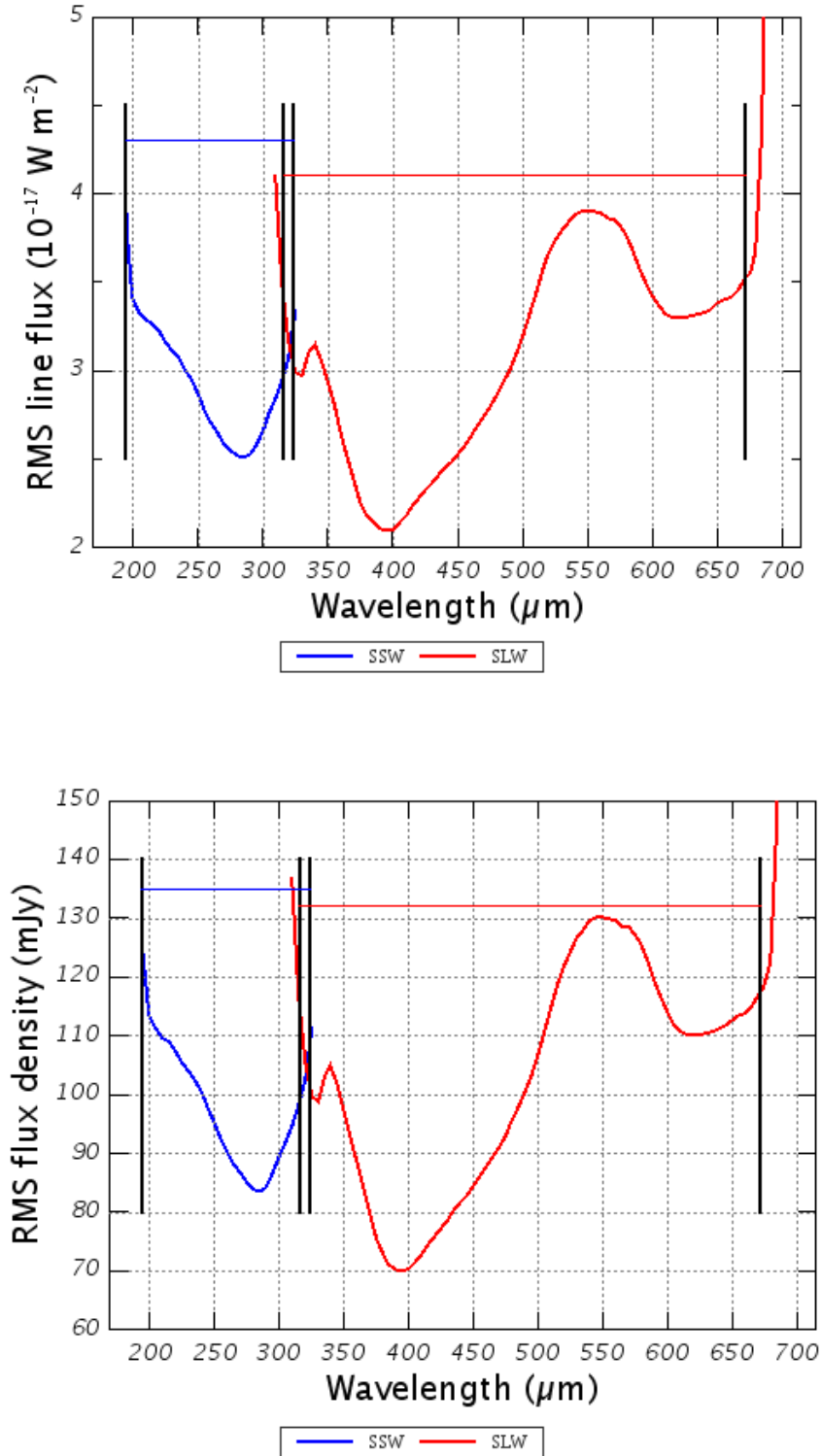
Figure 3.2. Top: unresolved spectral line rms flux sensitivity, 5 σ, 1 hour for point source. Both SSW (blue) and SLW (red) are shown as well as the operational ranges defined for the bands (indicated by the black vertical lines). These plots apply both to High and Medium resolution modes. Bottom: low resolution mode 5 σ, 1 hour point source flux density limit vs. wavelength for SSW (blue) and SLW (red). The operational ranges defined for the bands are indicated by the vertical lines. For Medium and High resolution modes, the flux density limits must be multiplied by 4 and 25 respectively.

3.2. Some examples

A full description of HSpot and its use is given in [The HSpot Users' Guide](#) and a number of examples for preparing observation requests are given in Chapter 6. Here we provide a few examples to indicate some kinds of observations that may become standard for may purposes.

3.2.1. Point source photometry

For many point source observations, we envisage the following standard parameters to be adopted:

Table 3.2. SPIRE Photometer point source photometry.

Number of repeats	1
On-source integration time (s)	256
Instrument and observing overheads (s)	143
Observatory overhead (s)	180
Total observation time (s)	579
1 σ noise (250, 350, 500) (mJy)	(1.4, 1.6, 1.3)

Note that this produces rms flux density limits that are already lower than the extragalactic confusion limits.

3.2.2. Small map

Small map observations cover a 4x4 arcmin area. The following are typical examples:

Table 3.3. SPIRE Photometer small map.

Number of repeats	1	2
On-source integration time (s)	256	512
Instrument and observing overheads (s)	251	443
Observatory overhead (s)	180	180
Total observation time (s)	687	1135
1 σ noise (250, 350, 500) (mJy)	(4.7, 6.3, 5.3)	(3.3, 4.5, 3.8)

With two repeats, the rms flux density limits are already getting close to the confusion limits. So one or two repeats should be adequate for most Small Map observations.

3.2.3. Large map

Maps larger than 4x4 arcmin in size are currently executed in Large Map mode. The default large map mode is to perform cross-linked scans in two orthogonal scan directions. Some examples are given below for both the default cross-linked scans and single scan direction modes at two different scan speeds: nominal (30"/s) and fast (60"/s):

Table 3.4. SPIRE Photometer large map examples. Cross-linked scans (A+B).

Scan speed (arcsec/s)	30	30	60	60
Map size (arcmin)	12x12	30x30	12x12	30x30

Number of repeats	1	1	1	1
On-source integration time (s)	256	944	128	472
Instrument and observing over-heads (s)	354	651	424	791
Observatory overhead (s)	180	180	180	180
Total observation time (s)	790	1775	732	1443
1 σ noise (250, 350, 500) (mJy)	(9.6, 13.2, 11.2)	(9.6, 13.2, 11.2)	(13.5, 18.6, 15.8)	(13.5, 18.6, 15.8)

Table 3.5. SPIRE Photometer large map examples. Single scans (A or B).

Scan speed (arcsec/s)	30	30	60	60
Map size (arcmin)	12x12	30x30	12x12	30x30
Number of repeats	1	1	1	1
On-source integration time (s)	128	472	64	236
Instrument and observing over-heads (s)	185	339	218	406
Observatory overhead (s)	180	180	180	180
Total observation time (s)	493	991	462	822
1 σ noise (250, 350, 500) (mJy)	(13.5, 18.6, 15.8)	(13.5, 18.6, 15.8)	(19.1, 26.3, 22.3)	(19.1, 26.3, 22.3)

From these examples one can see:

- The sensitivity for one map repeat does not depend on the map size so it is necessary to increase the repetition factor in order to achieve better resolution.

- For cross-linked scan (A+B) the repetition factor refers to the number of A+B pairs of map repeats.

- Fast scanning mode is only sensible for large maps (several square degrees) else the overheads are too large making the observation too inefficient.

3.2.4. FTS Examples

Table 3.6. FTS point source/sparse map; high resolution

Number of repeats	2	4	8
On-source integration time (s)	266	533	1066
Instrument and observing overheads (s)	116	119	126
Observatory overhead (s)	180	180	180
Total observation time (s)	562	832	1372
1 σ noise (10^{-17} W m^{-2})	1.5 - 2.9	1.1 - 2.1	0.8 - 1.5
Comment	Not very efficient	Relatively efficient	Much more efficient

Note that the observing overheads are much smaller than for any of the photometer modes as the telescope is not moved in the course of the observation.

Table 3.7. FTS point source/sparse map; low resolution

Number of repeats	20	40
On-source integration time (s)	256	512
Instrument and observing overheads (s)	152	192
Observatory overhead (s)	180	180
Total observation time (s)	588	884
1 σ noise (mJy)	52-99	37-70
Comment	Not very efficient	Much more efficient

Note

Due to the fixed overheads involved in setting up the instrument for a series of scans, observations become more efficient when long scan sequences are implemented (for example, either by using a large number of repetitions, or high spectral resolution mode, which uses long scans). The least efficient observing configuration (although still useful in some circumstances) is a single pointed, low resolution observation with only two scan pairs (repeats).

Chapter 4. Observing with SPIRE

An observation with SPIRE (or any of the Herschel instruments) is performed following an Astronomical Observation Request (AOR) made by the observer. The AOR is constructed by the observer by filling in the so called Astronomical Observation Template (AOT) in the Herschel Observation Planning Tool, HSpot. Each template contains options to be selected and parameters to be filled out, such as target name and coordinates, observing mode etc. Once the astronomer has made the selections and filled in the parameters on the template, the template becomes a request for a particular observation, i.e. an AOR. If the observation request is accepted via the normal proposal-evaluation-time allocation process then the AOR content is subsequently translated into instrument, telescope/spacecraft commands which are up-linked to the observatory for the observation to be executed.

There are two[1] Astronomical Observation Templates available for SPIRE: one for doing photometry with the Photometer and one for using the Spectrometer to do imaging spectroscopy at high, medium or low spectral resolution.

This chapter explains the SPIRE AOTs and the details of the observing modes that are used to perform the observations, Chapter 3 gives details on the sensitivities of the different observing modes, the HSpot Users' Guide describes how to enter observations into HSpot and Chapter 6 gives cookbook style examples of how to prepare observations.

> **Note**
>
> During one Herschel observing day, only one of the two SPIRE sub-instruments can be used to make observations. Therefore it is not possible to concatenate an observation using the photometer with one of the spectrometer, or vice versa, see the Herschel Observers' Manual.

Building Blocks   Observations are made up of logical operations, such as configuring the instrument, initialisation and science data taking operations. These logical operations are referred to as building blocks. The latter operations are usually repeated several times in order to build up S/N and/or to map an area of sky. Pipeline data reduction modules work on building blocks.

The following operations are part of AOTs/AORs and constitute building blocks depending on the observing mode:

PCAL   During SPIRE observations, it is envisaged that the photometer calibration source, PCAL, will be operated at intervals to track any responsivity drifts. Each such operation will require on the order of 10 seconds, and a frequency of around once per 45 minutes is thought to be adequate. To ensure that response to the modulated astronomical sky is not confused with response to PCAL, the BSM and telescope positions must be held steady while PCAL is being modulated. We assume an average slew time of three minutes, so the on-source integration time should be comparable or greater than this value to avoid highly inefficient use of time. This means that PCAL operation at the start and end of the observation will result in a relatively small loss of observing time, with the benefit of having calibration information included in the data set for each observation.

Nodding   Nodding is performed to subtract the different amounts of ambient background power received by the detector at the two different chop positions. This is done by using the NOD function of the telescope which is an operation in which the target source is periodically moved from one instrument chop position to the other chop position by re-

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[1]There is a third observing template which includes SPIRE and it is for doing photometry in parallel mode with one of the other Herschel instruments - PACS. See SPIRE PACS Parallel Mode Observers' Manual.

pointing the satellite, as shown in Figure 4.1.

For a given detector, chopping with the BSM creates two beams, designated left (L) and right (R). In nod position A, the source is placed in beam R, and in nod position B it is placed in beam L. Due to thermal emission from the telescope and the ambient surroundings, each beam will have an offset signal, O_L or O_R, which are slightly different for the two beams due to inevitable slight asymmetries in the optical system and the background thermal radiation field. Furthermore, these offsets can be a function of time - for instance, due to temperature drifts which might change the two offsets in a different way. The purpose of nodding is to subtract out these offsets, and to do so on a timescale faster than any such drifts.
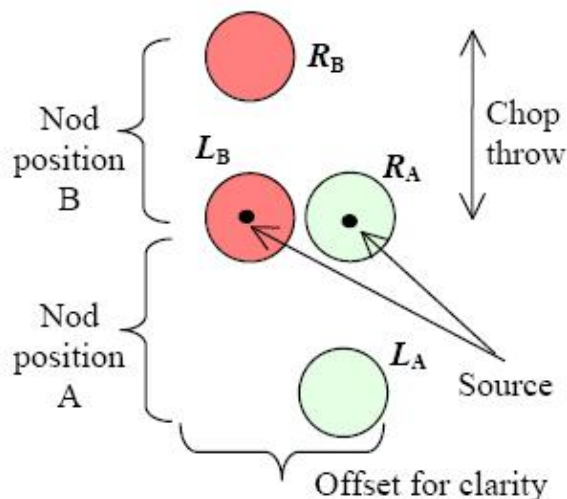
Figure 4.1. Nodding and removal of signal offsets

4.1. SPIRE Photometer AOT

This SPIRE observing template uses the SPIRE photometer (Section 2.2) to make simultaneous photometric observations in the three photometer bands (250, 350 and 500 µm). It can be used with three different observing modes:

- **Point Source Photometry:** This mode is for photometric observations of isolated point sources. It uses chopping, jiggling and nodding, observing the source at all times.

- **Small Map Photometry:** This is for sources or areas smaller than 4 x 4 arcmin. The guaranteed observed area is a 4 arcmin diameter circle. Chopping and nodding are used.

- **Large area or extended source mapping:** This mode is for mapping sources larger than a 4 arcmin diameter circle, or to cover large areas of sky. The map is made by scanning the telescope.

PCAL observations are performed during these observations (see PCAL).

4.1.1. Point Source

Usage: This observing mode should be used to make an observation of an isolated compact (point) source with well known coordinates.

Description: This incorporates 7-point jiggling to ensure to be able to reconstruct the signal flux. Chopping and nodding are performed to spatially modulate the signal and to remove background differences.

Details: A mini-map is made around the nominal position to make sure that the source signal and position can be estimated. This mini-map is made by moving the BSM around to make the 7-point jiggle map as shown in Figure 4.2 for one detector. The 7-point map is made by observing the central position and then moving the BSM to observe six symmetrically arranged positions, offset from the central position by a fixed angle (nominally 6 arcsec), and then returning to the central point once more (note that the 7 in 7-point refers to the number of different positions). At each of these positions chopping is performed between sets of co-aligned detectors (Figure 4.3) to provide spatial modulation and coverage in all three wavelength bands (Section 2.2). The chop direction is fixed along the long axis of the array (Y), and the chop throw is 126 arcsec. The nominal chop frequency is 2 Hz. Sixteen chop cycles are performed at each jiggle position. Nodding, once every 64 seconds, is performed along the Y axis to remove differences in the background seen by the two detectors (see Nodding for details). Figure 4.3 shows the central row of co-aligned pixels, chopping and nodding will be performed between detector pairs (1,2).
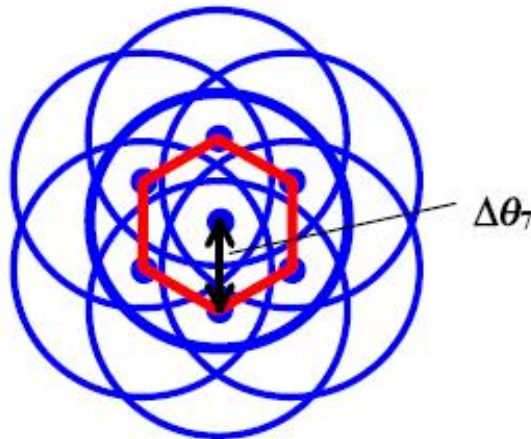
Figure 4.2. The 7-point hexagonal jiggle pattern. Note that the central position is re-visited at the end.

A point source photometry observation is made up of 7-point maps as building blocks. These are repeated at each nod position (first A then B - see Figure 4.1). The minimum nod pattern for this mode is ABBA (i.e. start at position A, then repeat position B twice, then return to position A). To acquire further integration time, the ABBA nod pattern is repeated an appropriate number of times: ABBA ABBA etc.

The chop and nod axis is parallel to the long axis of the array to allow switching between co-aligned pixels. As Herschel moves in its orbit, the orientation of the array on the sky changes. To avoid chopping nearby bright sources onto the arrays, pairs of angles can be defined (up to three pairs are allowed) which will prevent the observation being made when the long axis of the arrays lies between the specified angles. As chopping and nodding take place in opposite directions, both the specified angle range and its equivalent on the other side of the map (± 180 degrees) are avoided.

Setting a chop avoidance criterion means that an observation will not be possible during certain periods, and the number of days on which the observation can be made will be reduced from the number of days that the target is actually visible (visibility in HSpot does not take into account the constraint). In setting a constraint you will therefore need to check that it is still possible to make your observation and that you have not blocked out all dates. Note also that, as explained in the Herschel Observers' Manual, parts of the sky near the ecliptic plane do not change their orientation with respect to the array and therefore it is not possible to avoid chopping in certain directions.

A practical tip is to transform the pair of chop avoidance angles (A1, A2) to pairs of position angles of the Herschel focal plane. Then, with the help of the HSpot target visibility tool (see Figure 6.29), the days when the focal plane position angle does not fall between the derived angles can be identified. As the chopping is on the Y-axis then the pair of chop avoidance angles (A1,A2) corresponds to two pairs of Herschel focal plane position angles (PA1,PA2) = (A1, A2) ± 90, which have to be avoided (see the example in Section 6.6.2).
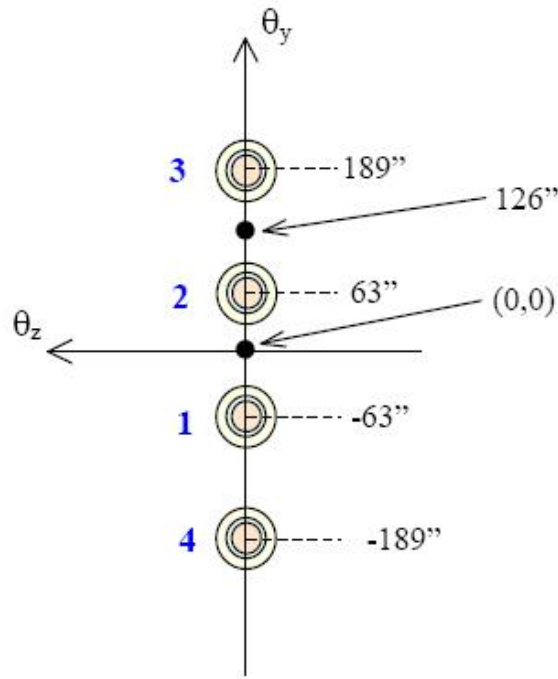
Figure 4.3. The image shows the central co-aligned pixels as they appear on the sky. The circles numbered 1 and 2 show the detectors on which a point source is viewed via the chopping and nodding which is described in detail in the text. The angular positions of detectors are also shown.

Warning

The constraints on when the observation can be performed make scheduling and the use of Herschel less efficient. The observer will be charged extra 10 minutes in overheads (rather than the usual 3) to compensate.

Although only the primary sets of co-aligned detectors are essential for this mode, the other detectors in the arrays will also be sampled, providing a sparse (undersampled) map of a roughly 2x4 arcmin region around the source.

User Input: Is listed in Table 4.1

Table 4.1. User input parameters for Photometer AOT with point source selected

Repetition factor:	The number of times the nod cycle ABBA is repeated to achieve the required sensitivity.
Number of chop avoidances:	An integer between 0 and 3.
Chopping Avoidance Angles From/To	To be used when number of chop avoidances is greater than zero. A From/To pair defines a range of angles to be avoided. Note that also the range ±180 degrees is also avoided. The interval is defined in equatorial coordinates, from the celestial north to the +Y spacecraft axis (long axis of the bolometer), positive East of North, following the Position Angle convention. This effectively defines an avoidance angle for the satellite orientation, and hence it is a scheduling constraint.

Source Flux Estimates (optional):	An estimated source flux density (in mJy) may be entered for a band, in which case the expected S/N for that band will be reported back in the Time Estimation. The sensitivity results assume that a point source has zero background. If no value is given for a band, the corresponding S/N is not reported back.

4.1.2. Small Map

Usage: This mode is for photometric mapping of objects or regions which are extended with respect to the individual SPIRE beam but smaller than 4 arcmin in size.

Description: This mode incorporates 64-point jiggling to provide a fully mapped area with chopping and nodding to spatially modulate the signal and to remove background differences.

Details: A 4 x 4 arcmin area is fully mapped by making a 64-point jiggle map with the BSM. The 4 x 8 arcmin field of view transmitted by the photometer optics is chopped and nodded by ±2 arcmin. The detectors in the central square 4 x 4 arcmin part of the array are alternately chopped from one side of the available field of view to the other. The detectors in the outer 4 x 2 arcmin portions at each end are chopped between the sky and the instrument cold box, producing no usable data. Hence this mode provides a map of area 4 x 4 arcmin. However only the sky within a circle of diameter 4 arcmin is guaranteed to be covered as the orientation of the detector arrays on the sky will depend on exactly when the observation is scheduled (see Figure 4.4). The observation is made up of building blocks corresponding to jiggle maps of 16 points. The 16-point jiggle map is repeated four times but at different jiggle positions to build up the 64-point map. At each of the 64 positions, four chop cycles are performed. After each jiggle map a nod movement is made (see Nodding) and then the 16-point jiggle map repeated at this nod position. Table 4.2 indicates how this is done. The minimum nod cycle for the small map mode is two positions (A and B) for every 16 points, hence for the 64-point jiggle map two ABBA cycles are performed. The integration time is increased by repeating the 64-point jiggle map.

User Input: the parameters entered by the user for this mode are summarised in Table 4.3.
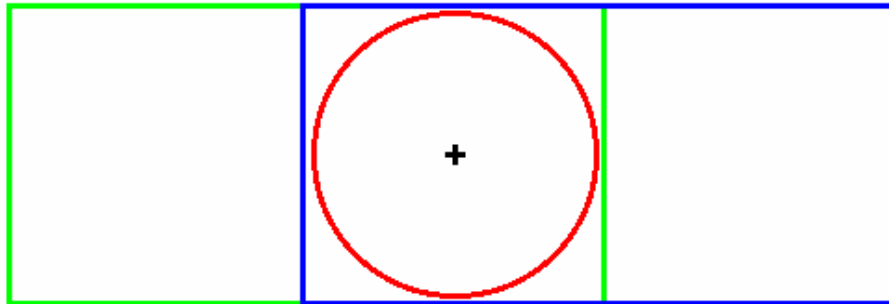

Figure 4.4. The blue and green rectangles of size 4 x 8 arcmin show the two nod position of the SPIRE Photometer (chopping is not shown). In the Small Map mode the nod distance is ±2 arcmin and the chopthrow is ±2 arcmin so that a central square region of size 4 x 4 arcmin is fully sampled by the 64-point jiggle. The red circle indicates the guaranteed area to be available independently of the observation date (the 4 x 4 arcmin square rotates depending on the Herschel focal plane position angle). The target position is marked with a cross.

Table 4.2. The build up of positions of the 64-point jiggle small map

Action	Jiggle Positions
Dwell on Nod Position A	1-16

Action	Jiggle Positions
Nod movement	
Dwell on Nod Position B	1-16
Dwell on Nod Position B	17-32
Nod movement	
Dwell on Nod Position A	17-32
Dwell on Nod Position A	33-48
Nod movement	
Dwell on Nod Position B	33-48
Dwell on Nod Position B	49-64
Nod movement	
Dwell on Nod Position A	49-64

Table 4.3. User input parameters for Photometer AOT with small map selected

Repetition factor:	The number of times the full area is repeated to achieve the required sensitivity.
Number of chop avoidances:	An integer between 0 and 3.
Chopping Avoidance Angles From/To:	To be used when number of chop avoidances is greater than zero. A From/To pair defines a range of angles to be avoided. Note that also the range ±180 degrees is also avoided. The interval is defined in equatorial co-ordinates, from the celestial north to the +Y spacecraft axis (long axis of the bolometer), positive east of north, following the Position Angle convention. This effectively defines an avoidance angle for the satellite orientation, and hence it is a scheduling constraint. See the previous section (Section 4.1.1) for more details.
Source Flux Estimates (optional):	An estimated source flux density (in mJy) and/or an estimated extended source surface brightness (MJy/sr) may be entered for a band, in which case the expected S/N for that band will be reported back in the Time Estimation. If no value is given for a band, the corresponding S/N is not reported back. The point source flux density and the extended source surface brightness are treated independently by the sensitivity calculations. The sensitivity results assume that a point source has zero background and that an extended source is not associated with any point sources. The time estimation will return the corresponding S/N, as well as the original values entered, if applicable.

4.1.3. Large Map

Usage: This mode is for photometric mapping of a large region of sky. All regions larger than a circle of 4 arcmin diameter should be observed with this option.

Description: The map is made by scanning the telescope to provide spatial modulation of the signal.

Details: The telescope is scanned at a given scan speed (*Nominal* at 30 arcsec/s or *Fast* at 60 arcsec/

s) along lines that are offset from each other to build up map coverage while providing some overlap between consecutive lines. As the SPIRE arrays are not fully filled, the telescope scans are carried out at a suitable angle with respect to the Z-axis of the arrays: ±42.4 degrees is the baseline value. It is possible to cover fields with both of these angles to perform cross linked scanning. This angle, along with the step size between consecutive line centres of 348 arcsec, has been selected to provide fully sampled maps as shown in Figure 4.5. Coverage maps for the cross scanning and single direction scanning for the different SPIRE bands can be found in Section 4.1.3.1.
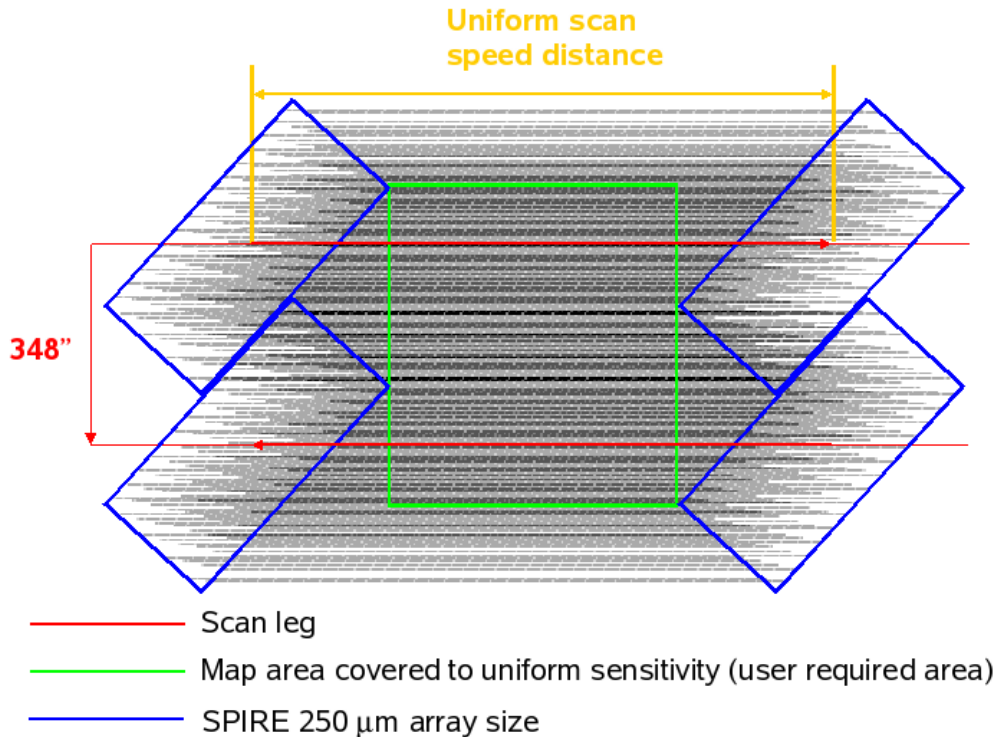
Figure 4.5. Large Map coverage showing the scan direction with respect to the SPIRE arrays, the scan leg step and the uniform sensitivity coverage region. The darker the shading the deeper the coverage.

Warning

Fast scanning is not efficient for small fields as the overheads become significant compared to the on-source time.

The possible scan directions are shown in Figure 4.6. One scan line corresponds to one building block. The default Large Map observation uses cross-linked scans, that is two scans at the two angles A and B with scan direction difference of 84.8 degrees. The default choice is to perform cross-linked scan maps: this is dictated by the fact that in cross-linked maps, the effect of 1/f noise on the map can be minimised. Fast scanning may be best for fields where one is interested in large scale structure as 1/f noise will be less significant at the faster scan speed.
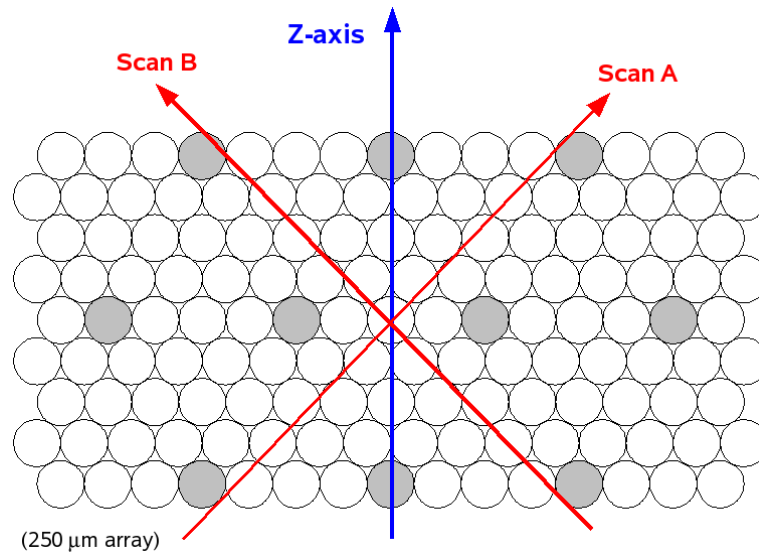
Figure 4.6. Large Map scan angles.

When 1/f noise is not an issue, the observer can chose either one of the two possible scan angles, A or B. The two are equivalent in terms of observation time estimation, overheads, sensitivities, but one may be favourable, especially when the orientation of the arrays of the sky does not vary much (due to either being near the ecliptic or to having a constrained observation, see below).

To build up integration time, the map is repeated an appropriate number of times. For a single scan angle, the area is covered only once. For cross-linked scanning, one repetition covers the area twice, once in each direction. Hence cross-linked scanning takes about twice as long and gives better sensitivity (see e.g. Table 3.5).

Cross-linked scanning is limited to an area of just under 4 degrees square, whereas single direction scans can be up to nearly 20 degrees in the scan direction and just under 4 degrees in the other direction. Hence with a single scan direction it is possible to make very long rectangular maps. The longest dimension of the map should be given first to reduce the number of scan legs needed in the observation and hence reduce the overheads. For cross-scan observations it does not matter which is specified first as the scans are done in both directions. Highly rectangular areas, however, become less efficient as many shorter scans are needed in one of the directions.

The dimensions of the area to be covered are used to set the length and number of scan legs. The scan length is set such that the area requested has good coverage throughout the map and that the whole array passes over all of the requested area with the correct speed. The number of scan legs is calculated to ensure that the total area requested by the user is observed without edge effects (a slightly larger area may be covered due to the discrete nature of the scans). Hence the actual area observed will be bigger than what was requested. The step size between the scan legs is set to 348 arcsec, which is the optimum spacing for the scan angle of 42.4 degrees (see above). The area is by default centred on the target coordinates; however this can be modified using map centre offsets (given in array coordinates). This can be useful when one wants to observe the core of an object plus part of its surroundings, but does not mind in which direction from the core the surrounding area is observed (see Section 6.6.5 for example).

The scans are carried out at a specific angle to the arrays, and the orientation of the arrays on the sky changes as Herschel moves in its orbit. The actual coverage of the map will rotate about the target coordinates depending on the exact epoch at which the data are taken (except for sources near the ecliptic plane where the orientation of the array on the sky is fixed: see the Herschel Observers' Manual). This is shown in Figure 4.7 for one scan direction and in Figure 4.8 for two scans.
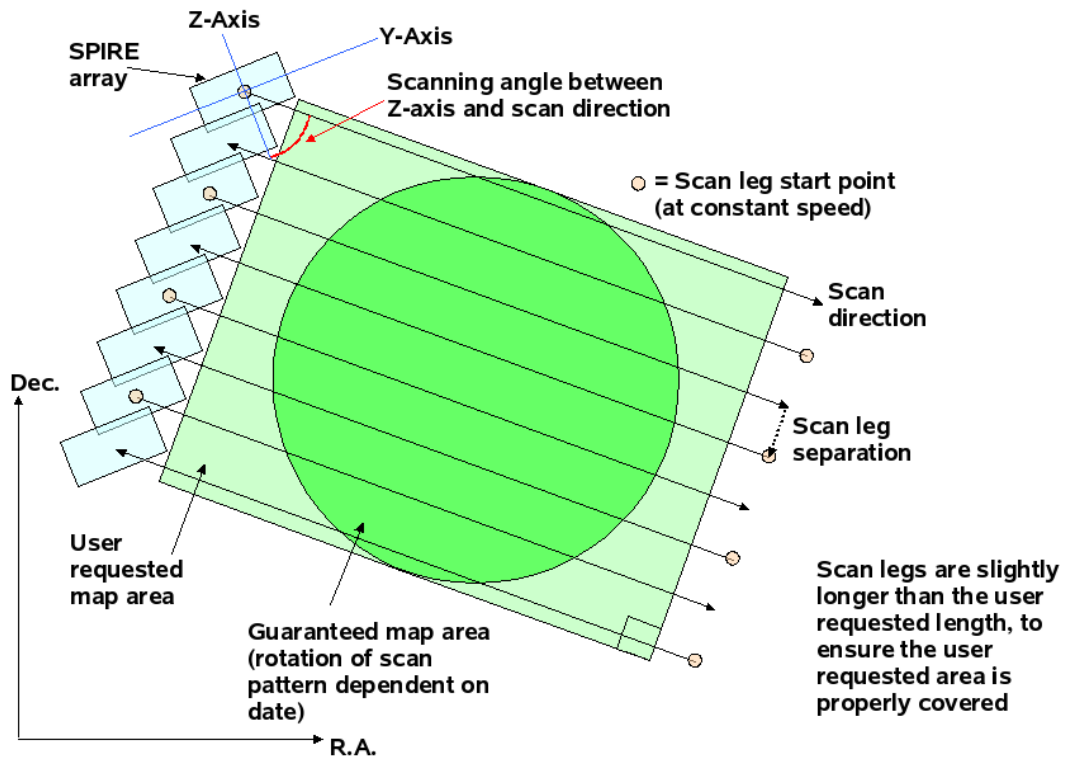
Figure 4.7. Large Map guaranteed area for one scan direction.

In addition to this, when performing cross-linked observations the area on the sky that is covered by both sets of scans is not quite rectangular: the corners of the map do not have dual coverage, as shown in green in Figure 4.8.

Hence, to guarantee that the piece of sky you want to observe is included in the map, you can over-size the area to ensure that the whole of your area is included no matter what the date of observation. This works well for square-like fields, but for highly elongated fields the oversizing factor would be large (see for example Figure 4.8). To reduce the amount of oversizing needed for the map you can use the Map Orientation "Array with Sky Constraint" setting to enter a pair of angles *A1* and *A2* (which should be given in degrees East of North). The orientation of the map on the sky, with respect to the middle scan leg, will be restricted within the angles given. This reduces the oversizing, but the number of days on which the observation can be scheduled is also reduced.
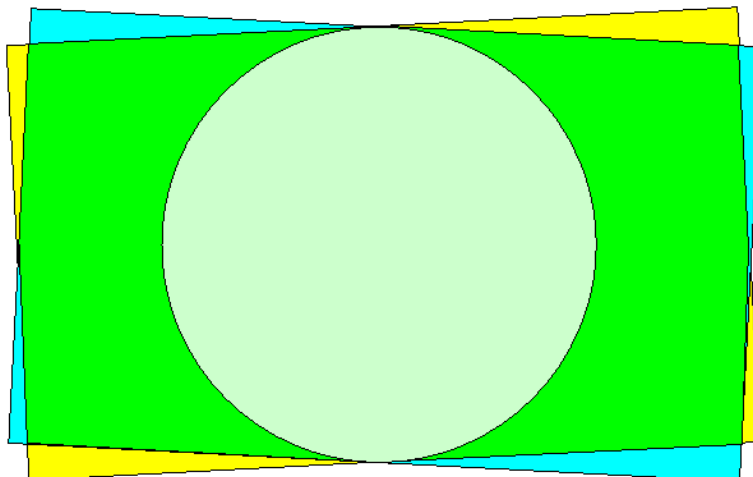
Figure 4.8. Large Map cross scanning at Scan Angles A and B, the coverages in the two directions are shown in different colours (yellow and cyan). The common cross linked scan coverage will be the green region. The light green circle indicates the guaranteed area of the map, which will be available regardless of the observing date.

Setting map orientation constraint is not taken into account in the visibility tool in the current HSpot release. A practical tip is to transform the pair of map constraints angles (A1, A2) to pairs of position angles of the Herschel focal plane. Then with the help of the HSpot target visibility tool the dates when the focal plane position angle is between the derived pairs can be checked (see the example in Section 6.6.6).

To transform a map angle to a position angle use the following expressions:

Equation 4.1.

```
Scan A:
        (PA1, PA2) = (A1, A2) - 42.4
        (PA1, PA2) = (180+A1, 180+A2) - 42.4
Scan B:
        (PA1, PA2) = (A1, A2) + 42.4
        (PA1, PA2) = (180+A1, 180+A2) + 42.4
```

Whenever the position angle of the Herschel focal plane is between all these four pairs of angles, the map orientation will be between A1 and A2 for the corresponding Scan A or Scan B scan leg direction. In some circumstances, for rectangular cross-linked maps, when the only available dates are in Scan B case, then it will be necessary to swap the length and the height of the map (see the example in Section 6.6.6).

Note also that as explained in Herschel Observers' Manual parts of the sky do not change their orientation with respect to the array and therefore it is not possible to set the orientation of the map in certain directions (the ecliptic) as the array is only orientated in one way on the sky. The constraints on when the observation can be performed make scheduling and the use of Herschel less efficient, hence the observer will be charged 10 minutes observatory overheads (instead of 3 minutes) to compensate (see the Herschel Observers' Manual).

Warning

Setting a Map Orientation constraint means that your observation can only be performed during certain periods, and the number of days that your observation can be made will be reduced from the number of days that the target is actually visible. In setting a constraint you will need to check that it is still possible to make your observation and that you have not blocked out all dates (see the example in Section 6.6.6).

User Input: the parameters entered by the user for this mode are summarised in Table 4.4.

Table 4.4. User input parameters for Photometer AOT with large map selected

Repetition factor:	The number of times the full map area is repeated to achieve the required sensitivity. For cross-linked maps (Scan Angles A and B), there are two coverages per repetition, one in each direction. For single scan direction observations (Scan Angle A or Scan Angle B), one coverage is performed per repetition.
Length:	This is the scan length of the map (in arcmin). It corresponds to the length in the first scan direction.
Height:	This is the size of the map (in arcmin) in the other dimension.

Scan speed:	This can be set as *Nominal*, 30"/s (the default value) or *Fast*, 60"/s.
Scan direction:	The choices are *Scan Angles A and B* (the default option, giving a cross-linked map), *Scan Angle A*, or *Scan Angle B*.
Map centre offset Y:	This is the offset (in arcmin) of the map centre from the input target coordinates along the Y axis of the arrays.
Map centre offset Z:	This is the offset (in arcmin) of the map centre from the input target coordinates along the Z axis of the arrays.
Map Orientation:	This can be set at either Array or Array with Sky Constraint. The latter option can be entered by selecting a range of map orientation angles for the observation to take place. The orientation angle is measured from the equatorial north to the direction of the middle scan leg direction positive east of north, following the Position Angle convention. The orientation constraint means a scheduling constraint and should therefore be used only if necessary.
Angle from/to:	In the case when Array with Sky Constraint is selected, the pair of angles (in degrees) between which the *middle* scan leg can lie along.
Source Flux Estimates (optional):	An estimated source flux density (in mJy) and/or an estimated extended source surface brightness (MJy/sr) may be entered for a band, in which case the expected S/N for that band will be reported back in the Time Estimation. The sensitivity results assume that a point source has zero background and that an extended source is not associated with any point sources. The point source flux density and the extended source surface brightness are treated independently by the sensitivity calculations. If no value is given for a band, the corresponding S/N is not reported back. The time estimation will return the corresponding S/N, as well as the original values entered, if applicable.

Note

The maximum allowed Length and the Height for a cross-linked large maps (Scan Angles A and B) are 226.0 arcmin for both dimensions. For scans in either Scan Angle A or Scan Angle B, the maximum Length is 1186.0 arcmin and the maximum Height is 240.0 arcmin.

4.1.3.1. Coverage Maps

Coverage maps for cross scanning and for single direction scanning for each of the three bands are shown in Figure 4.9.
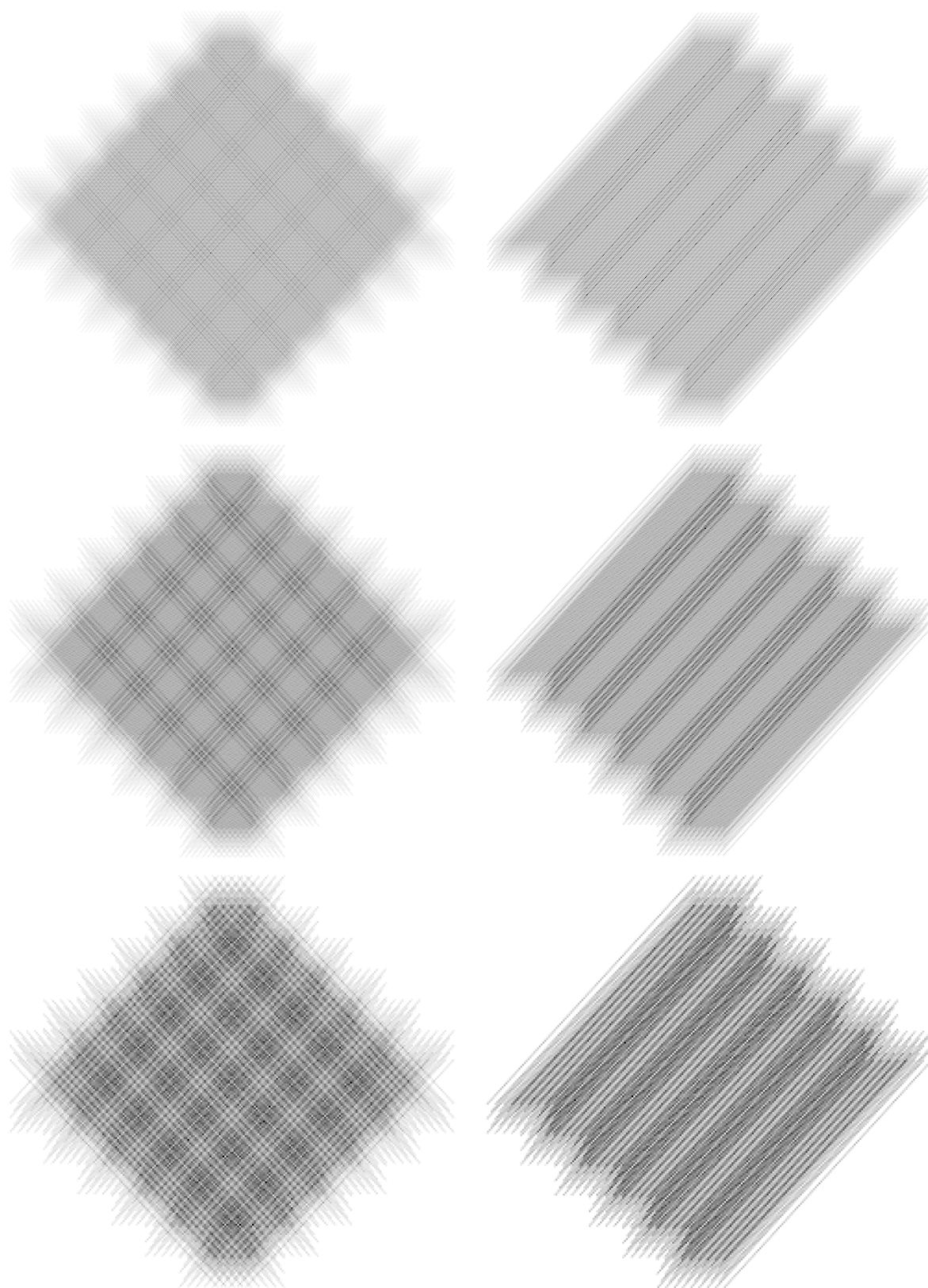
Figure 4.9. Coverage maps. Cross-scanning (left panels) and single scanning (right panels) for the three bands: 200 μm (top), 350 μm (middle) and 500 μm (bottom). The darker the shading the deeper the coverage.

4.2. SPIRE Spectrometer AOT

This observing mode is used to make spectroscopic observations with the SPIRE Fourier Transform Spectrometer (Section 2.3). The Spectrometer can be used to take spectra with different spectral resolutions:

- High resolution;

- Medium resolution;

- Low resolution;

- High and Low resolutions.

These spectra can be measured in a single pointing (using pixels within the field of view of the instrument) or in larger maps which are made by moving the telescope in a raster. For either of these, it is possible to choose sparse, intermediate, or full Nyquist spatial sampling. Hence to define an observation, one needs to select a spectral resolution, a pointing mode and an image sampling. These are described in the next sections. For worked examples of how to combine these modes together to produce observations see Chapter 6.

Here is a list of the possible spatial coverage options (pointing mode and image sampling) that are combined with a resolution setting to produce an observation type:

- Single pointing with sparse image sampling;

- Single pointing with intermediate image sampling;

- Single pointing with full image sampling;

- Raster map with sparse image sampling;

- Raster map with intermediate image sampling;

- Raster map with full image sampling.

4.2.1. Spectral Resolution

The Spectrometer Mirror Mechanism (SMEC) is scanned continuously at constant speed over different distances to give different spectral resolutions (see Section 2.3.1). For every repetition, two scans of the SMEC are done: one in the forward direction and one in the backward direction, making one scan pair, as shown in Figure 4.10. Two scan pairs are deemed essential for redundancy in the data. The desired integration time is set by increasing the number of scan pairs performed (corresponding to the number of repetitions entered in HSpot).
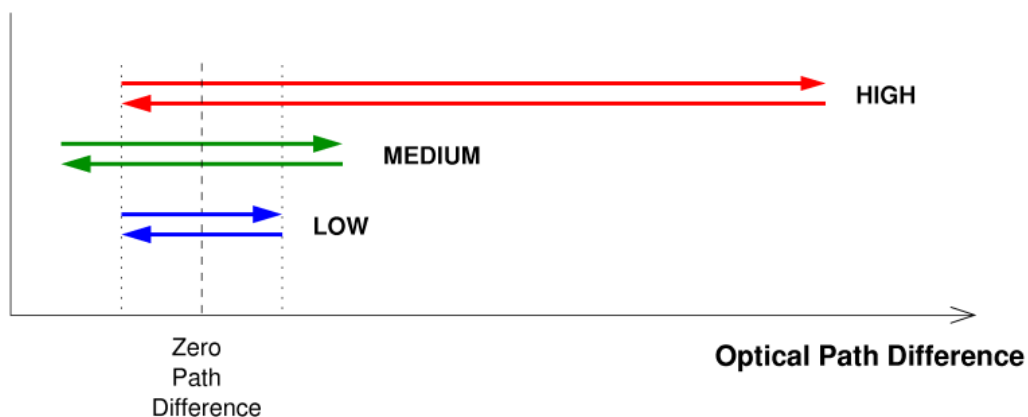
Figure 4.10. Diagram to show how the SMEC moves (in terms of optical path difference) during one re-petition for High, Medium and Low spectral resolution. The low resolution SMEC scan range is always covered during High or Medium resolution observations.

- **Low Resolution:**

  Usage and Description: To make continuum measurements at the resolution of 1 cm^{-1} ($\lambda/\Delta\lambda$ = 40 at λ = 250 μm). The SMEC is scanned symmetrically about ZPD over a short distance. It takes 6.4 s to perform one scan in one direction at this resolution.

- **Medium Resolution:**

  Usage and Description: This intermediate resolution of $\Delta\sigma$ = 0.25 cm^{-1} ($\lambda/\Delta\lambda$ = 160 at λ = 250 μm) will be more suited to broad features. Medium resolution scans are made by scanning the SMEC through the appropriate distance, larger than in the low resolution mode, symmetrically about ZPD. One scan in one direction takes 24.4 s.

- **High Resolution:**

  Usage and Description: This is to obtain spectra at the highest resolution available with the SPIRE spectrometer, $\Delta\sigma$ = 0.04 cm^{-1} which corresponds to $\lambda/\Delta\lambda$ = 1000 at λ = 250 μm. High resolution scans are made by scanning the SMEC to the maximum possible distance from ZPD. It takes 66.6 s to do one scan in one direction.

  Low resolution spectra are also extracted by the pipeline from high resolution observations. This is done during Stage 4 of the Spectrometer pipeline (see Section 7.2.3). Consequently, the equi-valent *low resolution* continuum rms noise (for the number of scan repetitions chosen) can also be recovered from a high resolution observation thus gaining on the low resolution continuum signal-to-noise. Note that this is not the case for medium resolution spectra, that is, no low resol-ution extraction is performed for medium resolution spectra.

  In cases when this extracted low resolution continuum level is not sufficient for the scientific case, the following "High and Low" resolution mode is introduced:

- **High and Low Resolution:**

  Usage: To make both line, and high S/N continuum spectra in a single observation (thus saving overhead time over two separate observations).

  Description: See also the individual entries of high resolution and low resolution. This mode al-lows the user to observe a high resolution spectrum as well as spending more integration time to increase the S/N of the *low resolution* continuum to a value higher than would be available from a high resolution observation on its own. Note that the numbers of high resolution and low resol-ution scans will differ in a way that depends on the required time (S/N) for each resolution.

If the number of repetitions for the high and low resolution parts are *nH* and *nL* respectively, then the achieved *low resolution* continuum sensitivity will correspond to *nH+nL* repetitions (because a low scan is also extracted from every high scan). It is up to the observer to decide if this mode, or a single high resolution observation is most suitable (in terms of sensitivities) for their scientific objectives. For examples of these considerations see Section 6.7.1.

4.2.2. Pointing Modes

A pointing mode and an image sampling are combined to produce the required sky coverage. Here the pointing modes are described.

- **Single Pointing Mode:**

  Usage: This is used to take spectra of a region smaller than the instrument's field of view (2.0 arcmin diameter circle unvignetted).

  Description: This is produced with one pointing of the telescope, hence only the field of view of the array on the sky is observed.

- **Raster Pointing Mode:**

  Usage: This is used to take spectra of a region larger than the field of view of the instrument (2.0 arcmin diameter circle unvignetted).

  Description: The telescope is pointed to various positions making a hexagonally packed map (see example in Figure 4.11). At each position, spectra are taken at one or more BSM positions depending on the image sampling chosen, determining how well the area is filled in.

  Details: The dimensions of the area to be covered determines the number of pointings in the map. The distances between these are 116 arcsec along the rows and 110 arcsec between the rows as shown in Figure 4.11. The number of pointings needed to cover the map is rounded up to ensure that the whole of the requested area is mapped. The area is by default centred on the target coordinates, however this can be modified by map centre offsets (given in array coordinates, see Photometer example of use of offsets Section 6.6.5).

  Note that for raster maps the target centre does not necessarily correspond to the centre of the detector array (use HSpot visualisation to see this). As the map is not circular and because the orientation of the array on the sky changes as Herschel moves in its orbit, the actual coverage of the map will rotate about the requested centre of the map (usually the target coordinates unless an offset is used) except for sources near the ecliptic (see the Herschel Observers' Manual). To force the actual area to be observed to be fixed or to vary less, the Map Orientation settings of "Array with Sky Constraint" can be used to enter a pair of angles (which should be given in degrees East of North) to restrict the orientation of the rows of the map to be within the angles given (see Chapter 6 for examples how to do this in HSpot).

  Setting a Map Orientation constraint means that your observation will not be able to be performed during certain periods, so the number of days that your observation can be made will be less than the number of days that the target is actually visible (target visibility does not take into account the constraint as it is a constraint on the observation, not the target itself). In setting a constraint you will need to check that it is still possible to make your observation and that you have not blocked out all dates. Note also that as explained in the Herschel Observers' Manual parts of the sky do not change their orientation with respect to the array and therefore it is not possible to set the orientation of the map in certain directions (the ecliptic) as the array is only orientated in one way on the sky. These constraints on when the observation can be performed make scheduling and the use of Herschel less efficient hence observer will charged extra overheads to compensate (see the Herschel Observers' Manual).

  Alternatively, raster observations can be split into several concatenated AORs to allow some tailoring of the coverage to match the source shape - see Section 6.7.3 for an example (but note that every concatenated AOR will be charged the 180 second slew tax).

User Input: The map parameters are similar to those for the Photometer Large Map. The Spectrometer parameters are listed in Table 4.5
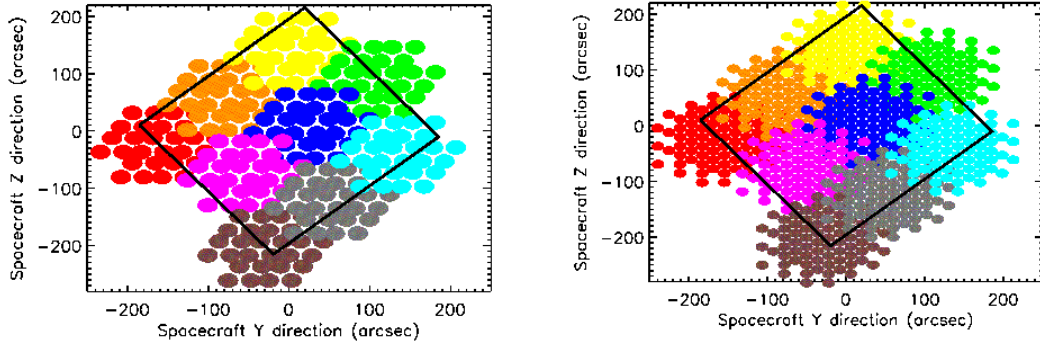

Figure 4.11. Spectrometer raster example to show spacing of the individual pointings for the long wavelength array (SLW, left) and the short wavelength array (SSW, right) for intermediate image sampling.

4.2.3. Image Sampling

A pointing mode and an image sampling are combined to produce the required sky coverage. Here the image sampling options are described and figures are given to show the sampling.

> **Warning**
>
> The figures show only the unvignetted pixels. It may be more difficult to calibrate the data from the non-central detectors.

- **Sparse Image Sampling:**

  Usage: To measure the spectrum of a point or compact source well centred on the central detectors of the Spectrometer. To provide sparse maps (either within the array with single pointing or larger than the array with a raster).

  Description: The BSM is not moved during the observation, producing a single array footprint on the sky. The result is an observation of the selected source position plus a hexagonal-pattern sparse map of the surrounding region with beam centre spacing of (32.5, 50.5) arcsec in the (SSW, SLW) bands as shown in Figure 4.12, upper left. For a point source this requires accurate pointing and good source position knowledge to be sure to have the source well in the (central) detector beam.

- **Intermediate Image Sampling:**

  Usage: This is to produce imaging spectroscopy with intermediate spatial sampling (1 beam spacing).

  Description: This gives intermediate spatial sampling without taking as long as a fully Nyquist sampled map. This is achieved by moving the BSM in a 4-point low frequency jiggle, giving a beam spacing of (16.3, 25.3) arcsec in the final map as shown in Figure 4.12, upper right. The input number of repetitions is performed at each of the 4 positions to produce the spectra.

- **Full Image Sampling:**

  Usage: This allows fully Nyquist sampled imaging spectroscopy of a region of sky or extended

source.

Description: This is achieved by moving the BSM in a 16-point jiggle to provide complete Nyquist sampling (1/2 beam spacing) of the required area. The beam spacing in the final map is (8.1, 12.7) arcsec as shown in Figure 4.12, bottom. The input number of repetitions is performed at each of the 16 positions to produce the spectra.
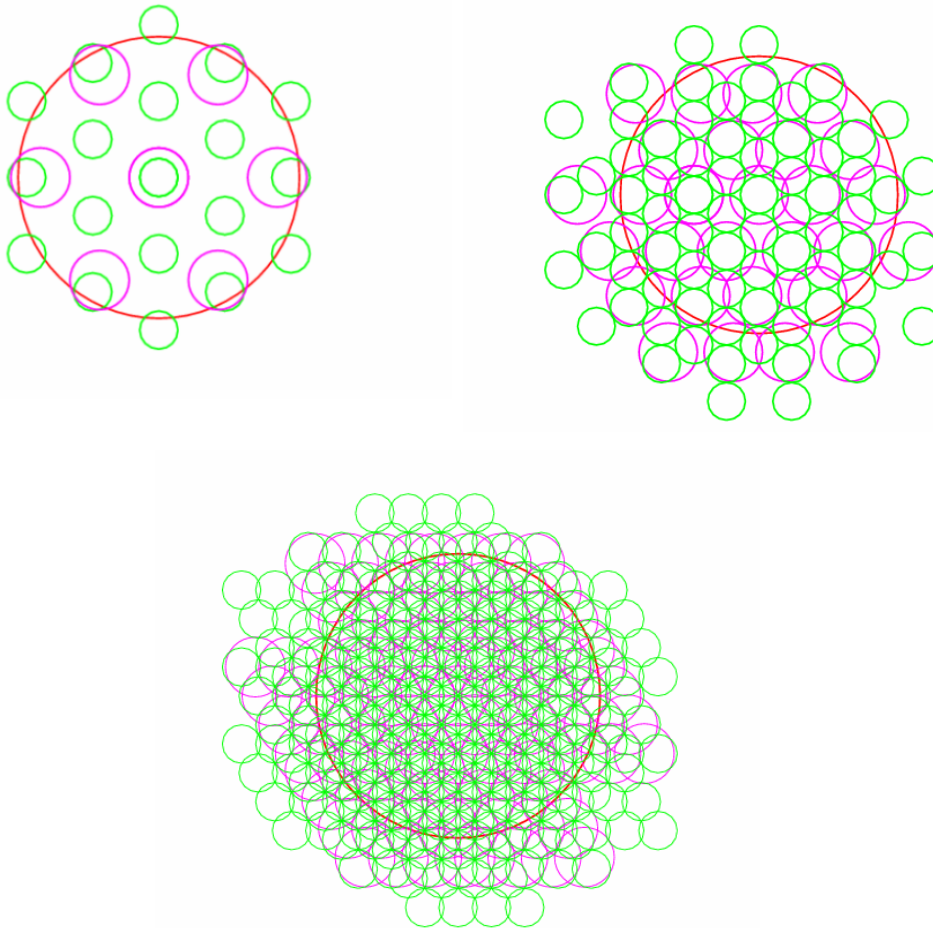
Figure 4.12. SPIRE Spectrometer spatial sampling. The small green and magenta circles indicate the regions where spectra will be observed for different spatial samplings. The green circles show SSW and the magenta show SLW, the large red circle of 2 arcmin diameter is to guide the eye. The upper row shows the sparse (left) and intermediate (right) sampling and the bottom figure shows the full sampling.

Table 4.5. User input parameters for Spectrometer AOT

Pointing Mode	Single Pointing or Raster selection. See description above for details. Note that if Raster is selected then size of the map (Length and Height) should be given.
Image Sampling	Sparse, Intermediate or Full selection. See description above for details
Spectral Resolution	High, Medium, Low or High and Low. See description above for details
Repetition factor	The number of spectral scan pairs to be made at each position. Note if High and Low resolution is selected you can independently control the number of pairs for

	each resolution.
Length	In arcmin. The length of the map along the rows.
Height	In arcmin. The height of the map.
Map centre offset Y	In arcmin. The offset of the map centre from the input target coordinates along the Y axis of the arrays
Map centre offset Z	In arcmin. The offset of the map centre from the input target coordinates along the Z axis of the arrays
Map Orientation	Either Array or Array with Sky Constraint. If Array with Sky Constraint is selected then range of the map orientation is constrained. This is a scheduling constraint and should therefore only be used if necessary.
Source Flux Estimates	Optional: if the estimated line flux in 10^{-17} W/m^2, and/or the estimated continuum (selectable units either Jy or 10^{-17} W/m^2/μm) is entered along with a wavelength then the expected S/N for that wavelength will be reported back in the Time Estimation as well as the original values entered. The time estimator always returns 1-σ flux sensitivity, 1-σ continuum sensitivity and unapodised resolving power for 8 standard wavelengths. Note, when Low resolution is selected only continuum information can be entered and returned (plus the unapodised resolving power). When High and Low resolution is selected data are returned for the two different resolutions.

Chapter 5. Calibration Framework

5.1. Calibration Requirements

The main calibration requirements are given in the table below.

Table 5.1. A summary of the main SPIRE calibration requirements, goals are given in brackets.

Absolute photometric accuracy at all wavelengths	15% (10%)
Relative photometric accuracy at all wavelengths	10% (5%)
Photometric linearity over dynamic range of 4000	5%
Optical field distortion/pixel positions	<10%
RMS detector NEP variation across any photometer array	<20%
Overlapping sets of detectors to be co-aligned within 2 arcsec (1 arcsec) on sky	

5.2. Strategy

The SPIRE Calibration Plan outlines all of the calibration tables that are needed to calibrate the astronomical data produced by SPIRE. For each table a measurement description, the phases in which these will be carried out - the instrument level tests (ILTs) and in-flight observations (commissioning, PV and routine phases) and the corresponding test/observing frequency are given. For the ILTs hot and cold blackbodies, a laser, the telescope simulator and the test facility FTS have been used for performing tests. The in-flight astronomical sources required for calibration observations are also given in Section 5.4.

5.3. On-board Calibrators

The SPIRE instrument contains two calibration sources, PCAL and SCAL. PCAL (see Section 2.2.4) is a photometric calibration source located in the pupil plane at the centre of the chopper which is used for spatial modulation of the sky, and is used for monitoring the responsivity of the detectors in both the photometer and the spectrometer. SCAL (see Section 2.3.3), the FTS calibration source, is a nulling source designed to cancel out the diluted blackbody spectrum of the telescope to reduce the required dynamic range of the detectors and to provide a reference comparator that has been accurately calibrated on the ground.

5.4. Astronomical Calibrators

To fulfil the SPIRE in-flight photometric calibration requirements, astronomical calibrators sources should ideally fulfil the following criteria:

- Have flux densities uncertainties well the SPIRE absolute accuracy requirement of 15% - preferably they should be known to $< 5\%$.

- Appear as point or compact sources ($< 1/3$ FWHM) in the SPIRE beams,

- Be either non-variable or have well modelled variability,

- Have suitable visibility for their use in the overall photometric calibration scheme.

- Have flux densities high enough to allow high S/N observations to be made, but not so high that significant problems arise in correcting for detector non-linearities.

For SPIRE, the primary flux calibrator is likely to be Uranus, although it is strong enough to cause slightly non-linear response. Neptune is also under consideration as the primary calibrator for the photometer. Asteroids and stars will be used as secondary calibrators, at least initially. These will fill in the middle and low flux ranges. There is a possible need for tertiary calibrators if the primary and secondary calibrators are not visible frequently enough for regular routine monitoring or if the instrument is not stable enough and the monitoring needs to be more frequent. Other possible flux calibration sources are the Galilean satellites, Titan, Pluto/Charon, planetary nebulae, bright IR galaxies.

For the spectrometer Uranus is likely to be the primary flux calibrator. A wavelength calibration is not necessary (de facto of FTS), but will be checked. Line flux calibration will be done with a standard set of lines.

5.5. SPIRE calibration products

These are low level calibration files which contain information on the behaviour of the different subsystems of the instrument. They are needed by the pipeline (see Chapter 7) in order to transform the raw telemetry data into calibrated scientific products.

Chapter 6. Using HSpot to Create SPIRE Observations

6.1. Overview

This chapter provides examples of how to create SPIRE observations within HSpot, the Herschel Observation Planning Submission Tool. Within HSpot we have two SPIRE AOTs, one for the Photometer and one for the Spectrometer (see Chapter 4 for details) each having different Observing Modes which are selected according to the source type to be observed. In this chapter we provide examples of how to set up simple and not so simple observations. These can be used as a guide to follow to help you enter your own observations into HSpot. The information presented here is split up into the SPIRE Photometer AOT and the SPIRE Spectrometer AOT. For each AOT there is a section on the components for setting up an observation and then sections per observing mode with worked example observations.

> **Note**
>
> The figures in this chapter were created on Linux platform and KDE desktop environment. For other operational systems (Windows, MacOSX etc.) and desktop managers, some slight differences in the appearance of the window decorations and style might be perceived.

6.2. Working with the SPIRE Photometer or Spectrometer Observation Template

Observations are generated by filling out AOTs (Astronomical Observations Templates), these AOTs lead you through the possible choices for setting up SPIRE so that the final request (an Astronomical Observing Request - AOR) contains all the necessary information for the observation to be made. There are two AOTs which are described in Chapter 4:

- SPIRE Photometer

- SPIRE Spectrometer

To choose one of the two AOTs go to the "Observation" pulldown menu at the top of the main screen that appears when HSpot is started up (see Figure 6.1).
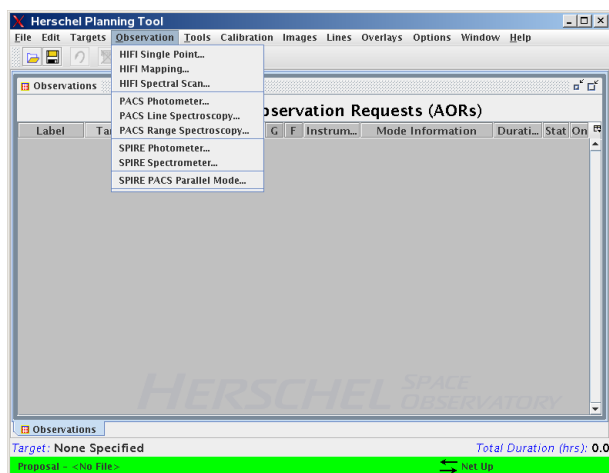
Figure 6.1. The main HSpot window.

To start preparing an observation pull down to " SPIRE Photometer..." or "SPIRE Spectrometer...". This starts up an AOT setup window. Figure 6.2 shows the Photometer AOT (see Figure 6.13 for the image of the Spectrometer AOT).
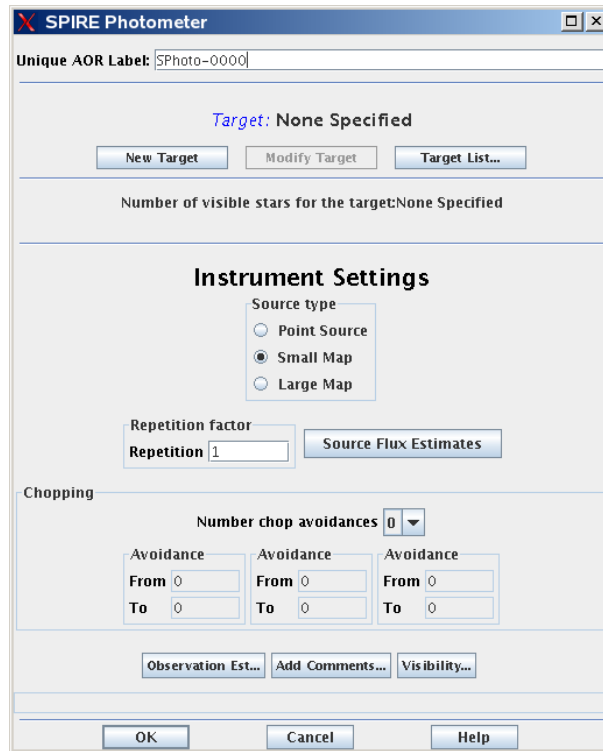
Figure 6.2. The Photometer AOT window on opening.

The AOT opens with a unique AOR label at the top, however you can edit it to make it more meaningful to yourself if you so wish.

The target of the observation can be entered in various ways (see the HSpot Users' Guide), one of which is directly into the AOT that is being prepared via the "New Target" button near the top. Press the button and then enter your target coordinates or the target name and resolve with SIMBAD or NED, or for solar system targets select the moving tab and enter target name and press "Resolve To Naif ID" or enter the Naif ID by directly, when you have finished press the "OK".

6.3. HSpot Components for Settings Up a SPIRE Photometer Observation

After following the steps of the previous section here are the components for setting up a Photometer observation with SPIRE.

6.3.1. Choosing the Source Type (Observing Mode)

The initial choice that you need to make is to decide which Source Type to use. This sets the Observing Mode to be used and is judged on the source extent or field size. The radio button list at the top of the main part of the screen (as shown in Figure 6.2) lists the three choices:

- Point Source

- Small Map

- Large Map

You should select "Point Source" for compact sources (less than 6 arcsec), "Small Map" for areas smaller than 4 arcmin in diameter and "Large Map" for areas larger than a circle of 4 arcmin diameter. These are described in Chapter 4. On selection of Large Map you will see the Chop Avoidance panel disappear and the Large Map Parameters panel appear as shown in Figure 6.3 (the use of these are described later in Section 6.3.5).
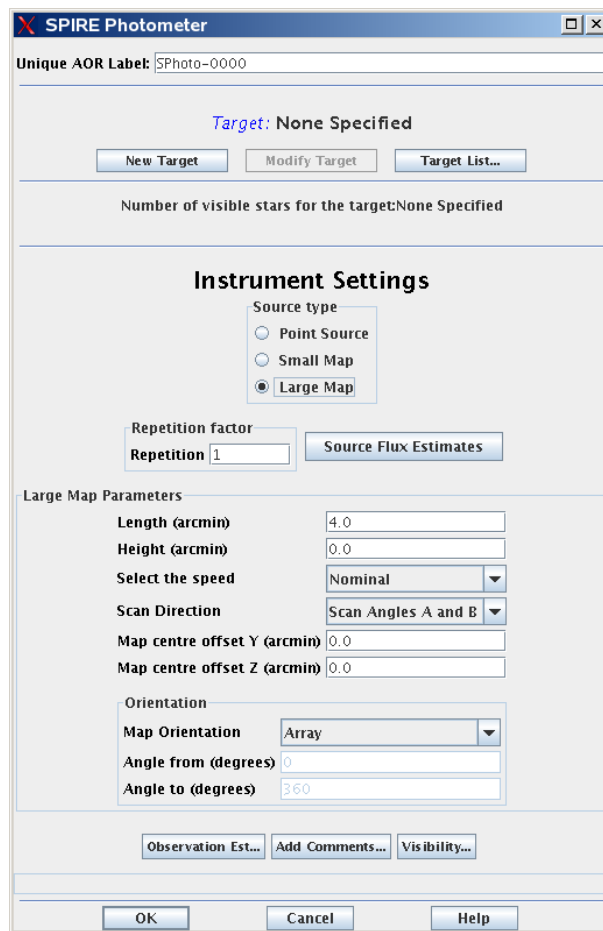
Figure 6.3. Photometer AOT with Large Map selected.

6.3.2. Setting the Repetition Factor - The Time of the Observation

The duration of the observation is controlled by the Repetition factor which is located under the Source Type list and shown in Figure 6.4. You should put in the box the number of repetitions you wish to carry out, where one repetition is:

- The number of ABBA nod cycles for Point Source

- The number of times to do the 64-point jiggle map for Small Map

- The number of times to repeat the area to be covered, in each direction, for Large Map. Note for Scan Angles A and B setting then one repetition is two coverages of the map, one in each direction. For a single Scan Angle (A or B) one repetition is one coverage of the area.

See Chapter 4 for more details. Note that for the Large Map mode the actual time taken depends on the size of the map as well. In Section 6.3.6 it is described how to see the actual duration using the Observation Estimates button.
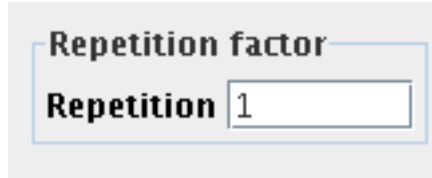
Figure 6.4. Repetition factor box.

6.3.3. Inputing Source Flux Estimates

Pressing the "Source Flux Estimates" button brings up a table in which you may enter details of your source. Note that it is optional to enter data here for zero to three bands, if you do enter information then you will be presented with signal to noise (S/N) information in the Observation Estimates result panel. This table depends on the Source Type selected, the Point Source table is shown in Figure 6.5 and the Small Map and Large Map one is shown in Figure 6.6. In the Point Source table you can enter values of "Estimated flux density (mJy)" in the boxes corresponding to the relevant wavelength bands. In the Small Map and Large Map table you can enter the Point Source flux density in mJy and the Extended source surface brightnesses in MJy/sr. Press "OK" once the appropriate values have been input. These values will be used for the noise estimate.
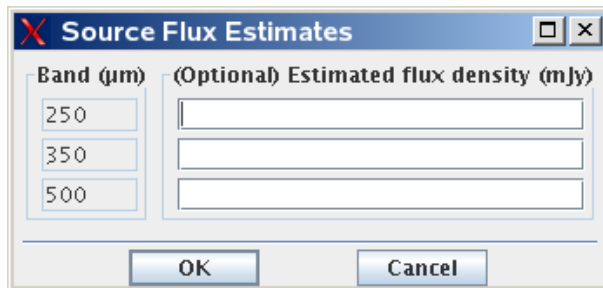
Figure 6.5. Source Flux Estimates Table for Point Sources.
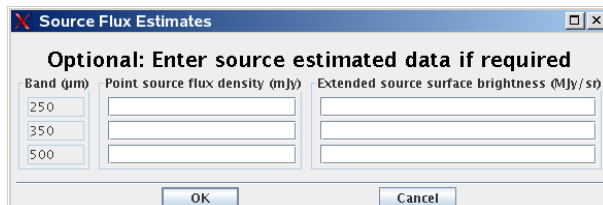
Figure 6.6. Source Flux Estimates Table for Small and Large Maps.

6.3.4. Setting Chop Avoidances in Chopping Panel for

Point Source and Small Map Observations

This option is only available when the source type "Point Source" or "Small Map" is selected. The panel is displayed in Figure 6.7 with one set of avoidance angles entered. To enter one or more chop avoidances you have to select the relevant number from the pulldown menu called Number of chop avoidances. This displays a warning (Figure 6.8) as by selecting 1, 2 or 3 you are setting a constraint on when your observation can be performed, so you should think about this carefully. Press "OK" to click away the warning and then the relevant number of Avoidance From and To boxes will be un-greyed allowing you to enter the relevant values of the angles that you wish to avoid.

If you want to avoid chopping on to a region at 20-40 degrees east of north then you should enter 20 in the From box and 40 in the To box as shown in Figure 6.7. Note if you want to avoid something to the north (say 350 to 10) then you should enter 350 in From and 10 in To. Also because of the nature of chopping the angles 180 degrees away from the pair you enter will also be avoided. It is very important that you visualise your observation at different dates to make sure that you observation is still possible (see the example in Section 6.6.2).

Figure 6.7. Photometer Chopping Panel for Point Source and Small Map with one chop avoidance selected and data entered.
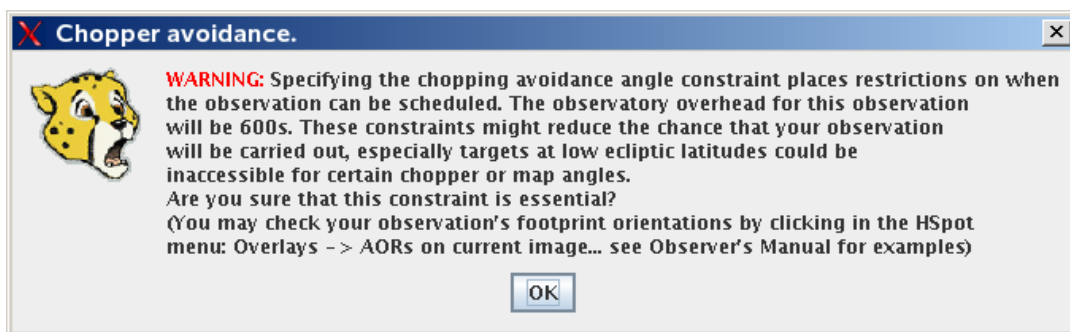
Figure 6.8. Warning message when one or more chop avoidance angles are requested.

6.3.5. Setting Parameters for Large Map Observations

This option is only available when the Source Type Large Map is selected. The panel is displayed in Figure 6.9.

Figure 6.9. Photometer Large Map Parameters Panel.

You should use this to enter the details of the area to be mapped. In the "Length" box you should enter the length of the area to be scanned, this is the length of the lines in arcmin that the telescope will scan along (note, the lines are actually great circles - see the Herschel Observers' Manual). The actual scans will be longer as acceleration and deceleration of the telescope will be outside of this. Also, as the array is scanned at an angle then the map edges will not be straight and hence the scan length is increased to make sure you get all of the array covering the required length. For single scan angles this parameter should be the larger one for rectangular maps (so that the telescope scans along the longest dimension thus less scans are needed to coverer the area thus the overheads for turning around the telescope are less). For two direction scanning (cross-linked scans) it does not matter which dimension is the smaller as the area is covered in both directions.

In the "Height" box you should enter the other dimension of your map in arcmin. From this the number of scans is calculated using the optimal scan leg spacing. Note that the number of scans needed will be rounded up to make sure that your dimension is fully covered.

You can select the speed at which the telescope is scanned, either "Nominal" or "Fast". "Nominal" is the default and the recommended value (currently set to 30 arcsec/s). "Fast" (60 arcsec/s) is good for maps with large scale structure as the 1/f noise will be less significant. Fast scanning is only sensible for large maps otherwise the observation time is dominated by overheads.

"Scan Direction" is used to select between cross-linked scanning and single direction scanning. Cross-linked scanning performed by covering the area in two directions, Scan Angles A and B. Single direction scanning can be performed by selecting either Scan Angle A, or Scan Angle B. For areas that do not change their angle much relative to the array, the selection of one of these angles over the other can help make make rectangular maps to be more efficient (by maximising as much as possible the scan legs to lie nearer to the longer dimension of the map)

If the target is not necessarily the centre of the map then map offsets can be used. These offsets in arcmin are given in detector Y, Z coordinates (see the example in Section 6.6.5 to understand the behaviour of the offsets).

As the orientation of the map on the sky rotates, unless you are on the ecliptic plane (see the Herschel Observers' Manual and Chapter 4), then the area you define rotates with time. To check this you should do a visualisation on different days. You can make sure that the area you want to map is covered by looking at the extent of the rotation and make your area bigger. However if the region you want to map is quite rectangular then you might like to consider setting a constraint rather than increase greatly the area to be mapped. You can set this constraint, effectively on when the observation can be observed, it means that the observation can only be scheduled when the orientation of the first scan legs of the observation (to see the first scan legs use Animate option in visualisation in HSpot) lie between the angles specified. This is selected via the Orientation box and selecting from the pulldown menu "Array with Sky Constraint". This displays a warning very similar to that for the chop avoidance which is shown in Figure 6.8. This warning is displayed as by selecting "Array with Sky Constraint" you are setting a constraint on when your observation can be performed, so you should think about this carefully. Press "OK" to click away the warning and then the "Angle From" and "Angle To" boxes will be ungreyed allowing you to enter the relevant values of the angles that you wish the scan legs to lie between. If you want the middle scan leg direction to lie between the angles 30 - 150 degrees east of north then you should enter 30 in the "Angle From" box and 150 in

the "Angle To" box. Note if you want the scan lines to lie in the direction to the north (say between 300 to 40 degrees) then you should enter 300 in the "Angle From" and 40 in "Angle To" box. It is very important that you visualise your observation at different dates to make sure that you observation is still possible (see the example in Section 6.6.6).

6.3.6. Getting Time and Noise Estimates

An accurate time estimate and associated noise estimate is obtained by clicking the "Observation Est..." button to bottom left of the AOT window. The software calculates the time that the observation should take and presents that in a new panel. If the values are okay for your science goals then click OK in this window and then OK on the main AOT window to complete the request. The Time Estimation Summary as shown in Figure 6.10 gives the returned information for when Point Source is selected.
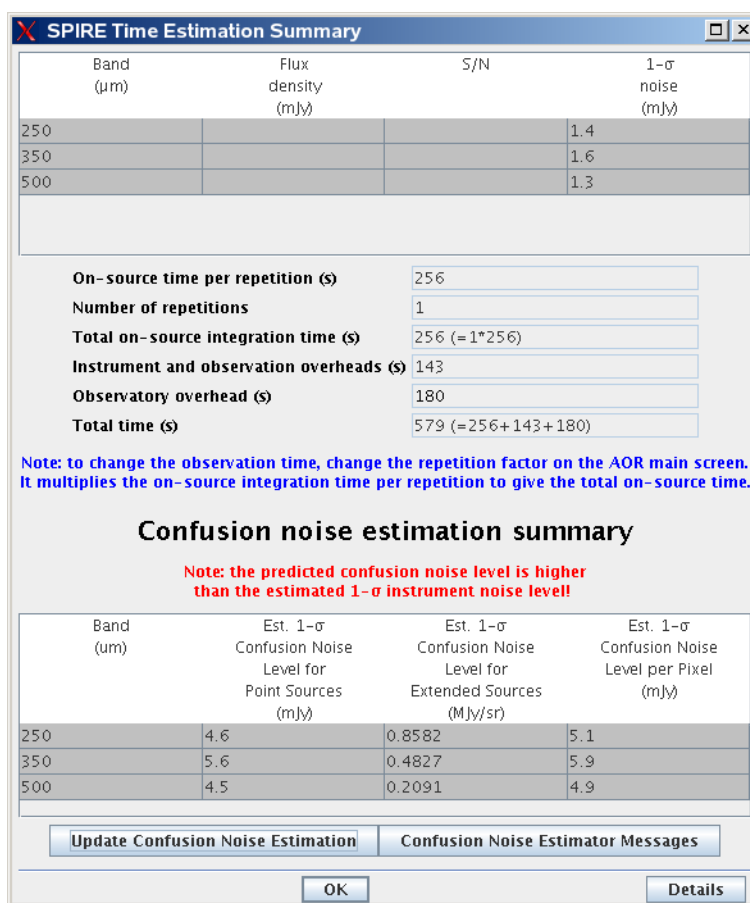
Figure 6.10. Time Estimation Summary for Photometer Point Source. Note here the button Update Confusion Noise Estimates has been pressed to obtains some estimates.

Figure 6.11 and Figure 6.12 show the results for the Source Type of Small Map and Large Map respectively. A 1-σ noise estimate for each SPIRE band is returned in the top table followed by a precise time estimate. The time estimate shows the total time of the observation and also the various components that contribute to the time.

If you entered Source Flux Estimates these will be reported in the table at the top as well as corresponding Signal to Noise information in the S/N column. You can get an estimate of the confusion noise too by pressing the "Update Confusion Noise Estimation" button. You are provided with more information on the observation by pressing the "Details" button in the bottom right of the Time Estimation Summary window.
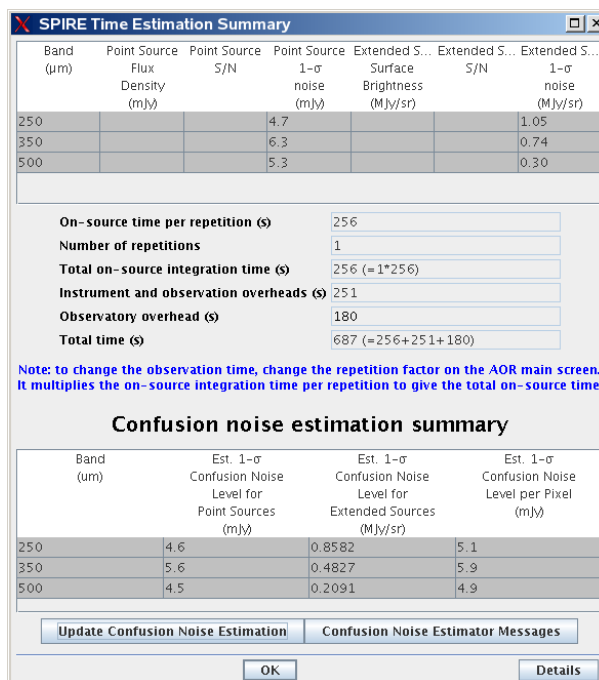
Figure 6.11. Time Estimation Summary for Photometer Small Map. Note here the button Update Confusion Noise Estimates has been pressed to obtains some estimates.
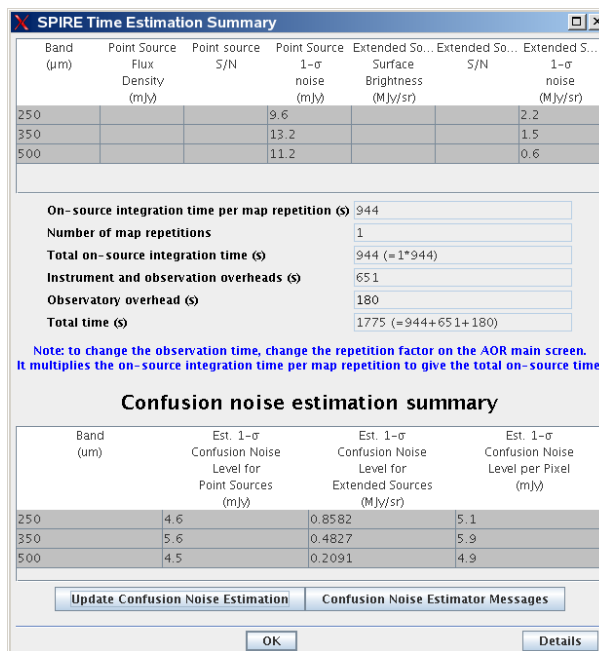
Figure 6.12. Time Estimation Summary for Photometer Large Map. The time estimation is for a 30x30 arcmin map with Scan Angles A and B and the Nominal scan speed selected. Note here the button Update Confusion Noise Estimates has been pressed to obtains some estimates.

6.4. HSpot Components for Settings Up a SPIRE Spectrometer Observation

After following the steps of Section 6.2 you will see the Spectrometer AOT. This is shown in Figure 6.13. The following sections describe the components for setting up a Spectrometer observation with SPIRE.
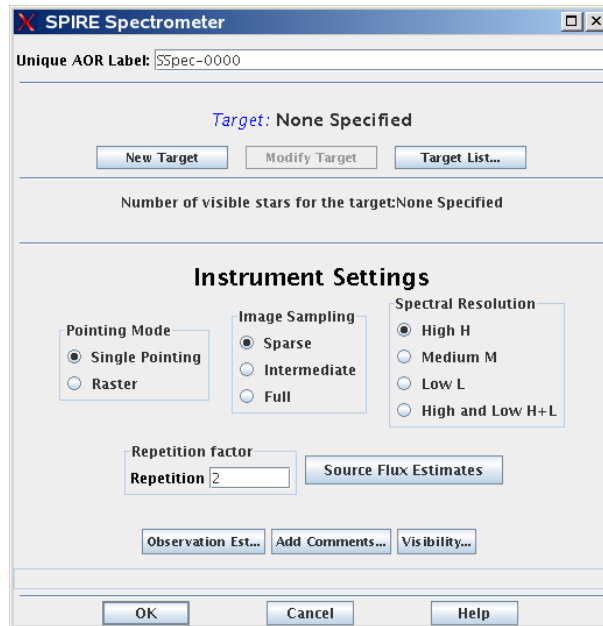
Figure 6.13. The Spectrometer AOT window on opening.

6.4.1. Choosing the Pointing Mode

The initial choice that you need to make is to decide which pointing mode to use. This is judged on the extent of the source or field to be observed. The radio button list at the top left of the main part of the screen (as shown in Figure 6.13) lists the two choices:

• Single Pointing

• Raster

You should select "Single Pointing" for areas smaller than 2 arcmin in diameter and "Raster" for areas larger than a circle of 2 arcmin diameter. These are described in Chapter 4. On selection of "Raster" you will see the "Raster Map Parameters" panel appear as shown in Figure 6.14 (the use of these are described later in Section 6.4.6).
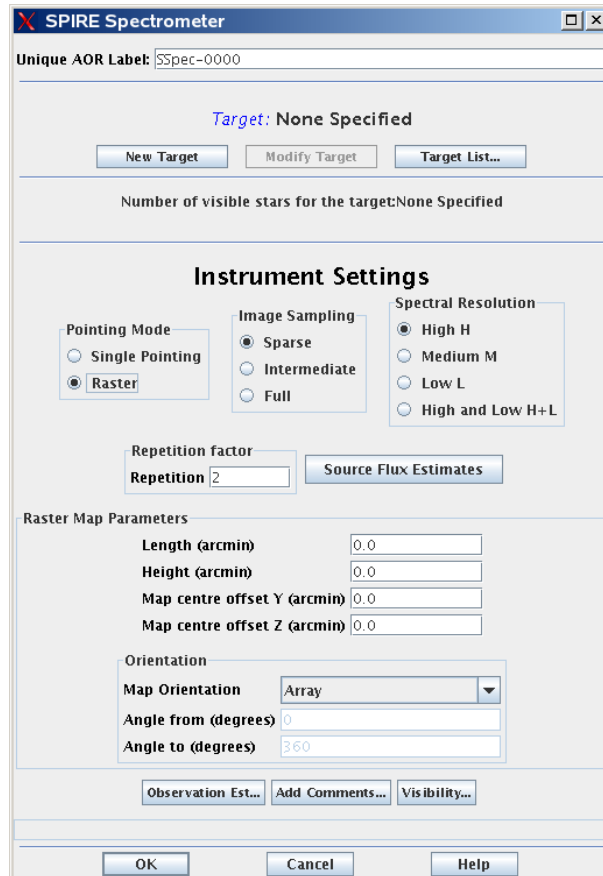
Figure 6.14. Spectrometer AOT with "Raster" selected.

6.4.2. Choosing the Image Sampling

The next choice that you need to make is to decide which image sampling to use. This is judged on the spatial sampling that is required for the observation. The radio button list (as shown in Figure 6.13) lists the three choices:

- Sparse

- Intermediate

- Full

You should select "Sparse" to measure the spectrum of a point or compact source well centred on the central detector of the Spectrometer or to provide a sparse map (2 beam spacing) of size 2 arcmin. Select "Intermediate spatial sampling" for an observation that has higher spatial sampling (1 beam spacing), without taking as long as a fully Nyquist sampled map. Or select "Full" for fully Nyquist sampled (1/2 beam spacing) imaging spectroscopy of a region of sky or extended source. These are described in Chapter 4.

6.4.3. Choosing the Spectral Resolution

The next choice that you need to make is to decide on the spectral resolution you require. The radio button list (as shown in Figure 6.13) lists the four choices:

- High

- Medium

- Low

- High and Low

As pointed out in Section 4.2.1, the choice of spectral resolution requires particular considerations because low resolution spectra can a posteriori be extracted from high resolution observations. You should select "High" for spectra at the highest resolution available with the SPIRE spectrometer, $\Delta\sigma$ = 0.04 cm^{-1}, "Medium" for a resolution of $\Delta\sigma$ = 0.25 cm^{-1}, or "Low" to make continuum measurements at a resolution of 1 cm^{-1}. The "High and Low" choice is to make both line, and higher sensitivity low resolution continuum spectra more efficiently (in a shorter time and in a single observation) than can be done by increasing the number of repetitions in "High" resolution observations. This is intended for sources where an observation in "High" resolution mode does not contain enough scan repetitions to achieve sufficient sensitivity in the *low resolution* continuum, and it is more efficient to add additional "Low" resolution scans (see the example in Section 6.7.1 for more details).

6.4.4. Setting the Repetition Factor - The Time of the Observation

The duration of the observation is controlled by the repetition factor which is shown in Figure 6.15. You should put in the box the number of repetitions you wish to carry out, where one repetition is:

- The number of spectral scan pairs (i.e. a value of 2 makes 4 spectra).

See Chapter 4 for more details.

Note that the actual time taken depends on the spectral resolution, the image sampling (and the size of the raster), as does the maximum value that can be entered. For Spectral Resolution "High and Low" two boxes appear allowing the number of scan pairs at each resolution to be controlled independently.

In Section 6.4.7 it is described how to see the actual duration using the "Observation Estimates" button.
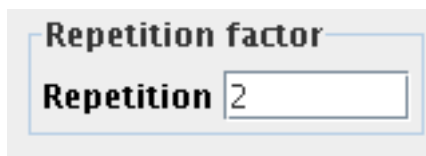
Figure 6.15. Repetition factor box for the Spectral Resolutions for High, Medium or Low.

6.4.5. Inputing Source Flux Estimates

Pressing the "Source Flux Estimates" button brings up a table in which you may enter details of your source. Note that it is optional to enter data here, you can enter data for zero to eight wavelengths, if you do enter information then you will be presented with an extra table in the Observation Estimates result panel with the signal to noise (S/N) information as calculated from the input values. The Source Flux Estimates input table depends on the Spectral Resolution selected, the High, Medium and "High and Low" Resolution table is shown in Figure 6.16 and the Low Resolution one is shown in Figure 6.17. In the High, Medium and "High and Low" Resolution table you can enter values of "Wavelength (μm)", "Estimated line flux (10^{-17} W/m^2)" and "Estimated Continuum". The units for the "Estimated Continuum" are selectable from the "Select Continuum Units"

pulldown menu, there is a choice between Jy (the default) and 10^{-17} W/m^2/μm. In the Low Resolution table you can enter Wavelength and Estimated Continuum as well as Select the Continuum Units. Press "OK" once the appropriate values have been input. These values will be used for the noise estimates.

Figure 6.16. Source Flux Estimates Table for High, Medium and "High and Low" Resolution.

Figure 6.17. Source Flux Estimates Table for Low Resolution.

6.4.6. Setting Map Parameters for Raster Observations

This option is only available when the Pointing Mode Raster is selected. The panel is displayed in Figure 6.18.

Figure 6.18. Spectrometer Raster Map Parameters Panel.

You should use this to enter the details of the area to be mapped. In Length you should enter the length dimension of the area to be mapped, this is the length of the raster rows in arcmin that the telescope will make the raster points along (note, the spacing of the raster points is 116 arcsec so to

control the number of raster points well you need to put in decimals of arcmin to avoid getting too many extra raster pointings as the number of pointings is rounded up).

In Height you should enter the other dimension of your map in arcmin. From this the number of raster rows is calculated using the optimal spacing of 110.6 arcsec. Note that the number of raster rows needed will be rounded up to make sure that your dimension is fully covered so again be careful to control the number of pointings using decimals of arcmin.

If the target is not necessarily the centre of the map then map offsets can be used. These offsets in arcmin are given in detector Y, Z coordinates (see the example in Section 6.6.5 to understand the behaviour of the offsets).

As the orientation of the map on the sky rotates, unless you are near the ecliptic plane (see the Herschel Observers' Manual and Chapter 4), then the area you define rotates with time. To check this you should do a visualisation at the extremes of a visibility window. You can make sure that the area you want to map is covered by looking at the extent of the rotation and make your area bigger. As the time to make, in particular, observations with High Spectral Resolution and Full Image Sampling can be long you might like to consider to set the Map Orientation constraint, or to spilt up your observation into several observations, see the example in Section 6.7.3. You can set this constraint on the orientation of the raster rows of your map via the Map Orientation box and selecting from the pulldown menu "Array with Sky Constraint". This displays a warning similar to that shown in Figure 6.8 as by selecting "Array with Sky Constraint" you are setting a constraint on when your observation can be performed, so you should think about this carefully. Press "OK" to click away the warning and then the Angle From and Angle To boxes will be ungreyed allowing you to enter the relevant values of the angles that you wish the raster rows to lie between. To see the raster rows use Animate of the visualisation, see HSpot Users' Guide for details. If you want the raster rows to lie between the angles 30 - 150 degrees east of north then you should enter 30 in the Angle From box and 150 in the Angle To box. Note if you want the raster rows to lie in the direction to the north (say between 300 to 40 degrees) then you should enter 300 in the Angle From and 40 in Angle To box. It is very important that you visualise your observation at different dates to make sure that you observation is still possible as the visibility windows do not take into account your constraints (see the example in Section 6.7.3).

6.4.7. Getting Time and Noise Estimates

An accurate time estimate and associated noise is obtained by clicking the "Observation Est..." button to bottom left of the AOT window. The software calculates the time that the observation should take and presents that in a new panel. If the values are okay to you then click OK and DONE on the main AOT window to complete the request. The Time Estimation Summary as shown in Figure 6.19 gives the return information for the default Spectrometer observation (with the following values selected Single Pointing, Sparse and High and a Repetition factor of 2).
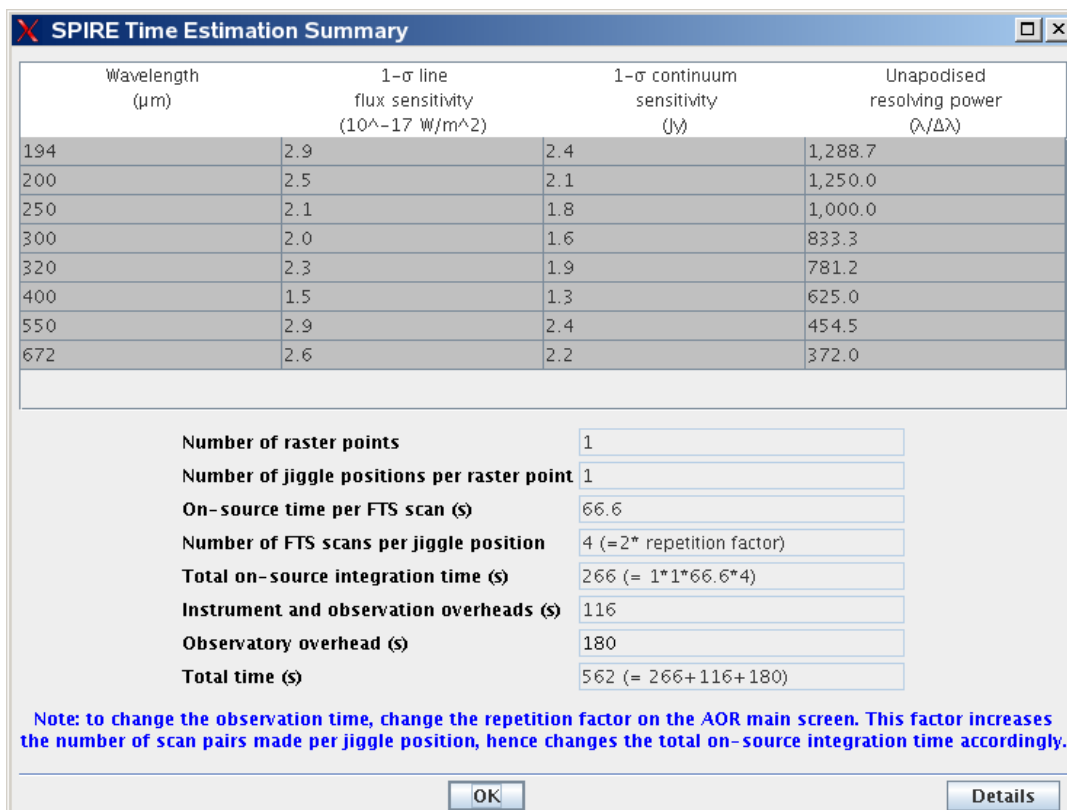
Figure 6.19. Time Estimation Summary for Spectrometer Default observation: single point, sparse, high resolution with 2 repetitions. The format of the window is the same for Medium resolution, however the values are different.

Figure 6.20 and Figure 6.21 show the results for the Spectral Resolution of "Low" and "High and Low" respectively. The 1-σ flux sensitivity (for all resolutions except "Low"), the 1-σ continuum sensitivity and the unapodised resolving power for each of eight standard wavelengths is returned in the top table followed by the time estimate. The time estimate shows the total time of the observation and also the various components that contribute to the time. If you entered Source Flux Estimates these will be reported in a second table as well as corresponding Signal to Noise information in the S/N column.

You are provided with more information on the observation by pressing the "Details" button in the bottom right of the Time Estimation Summary window.
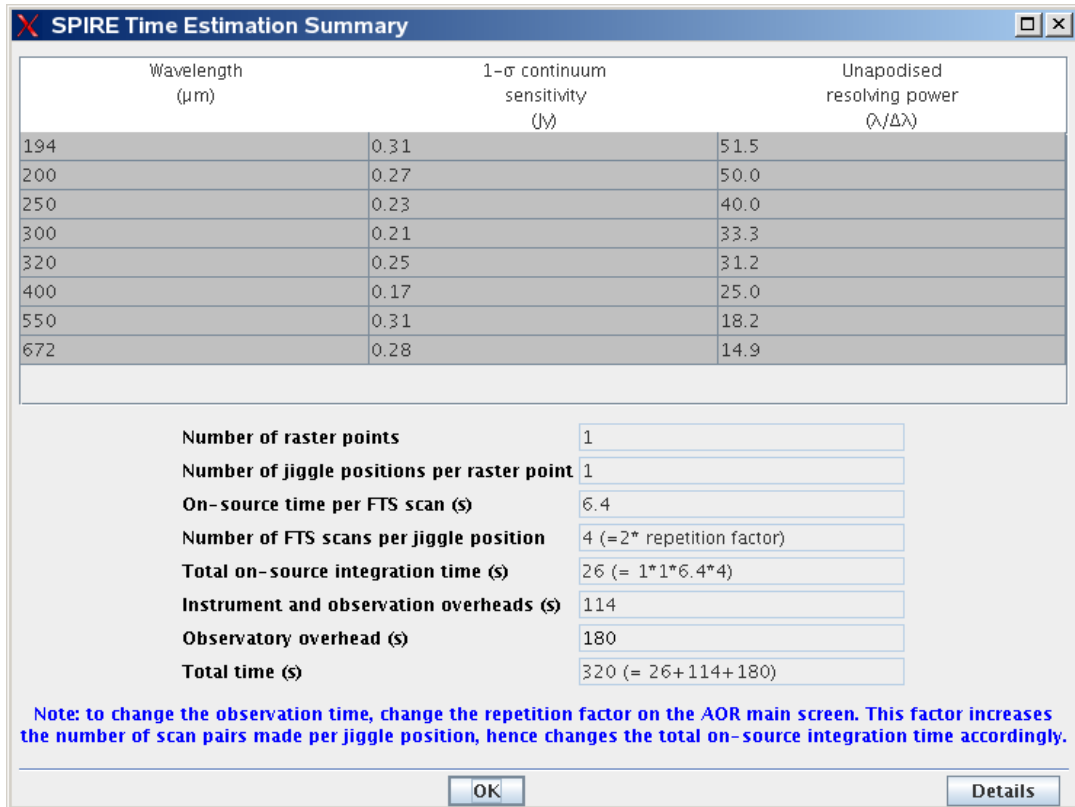
Figure 6.20. Time Estimation Summary for Spectrometer Low Resolution.
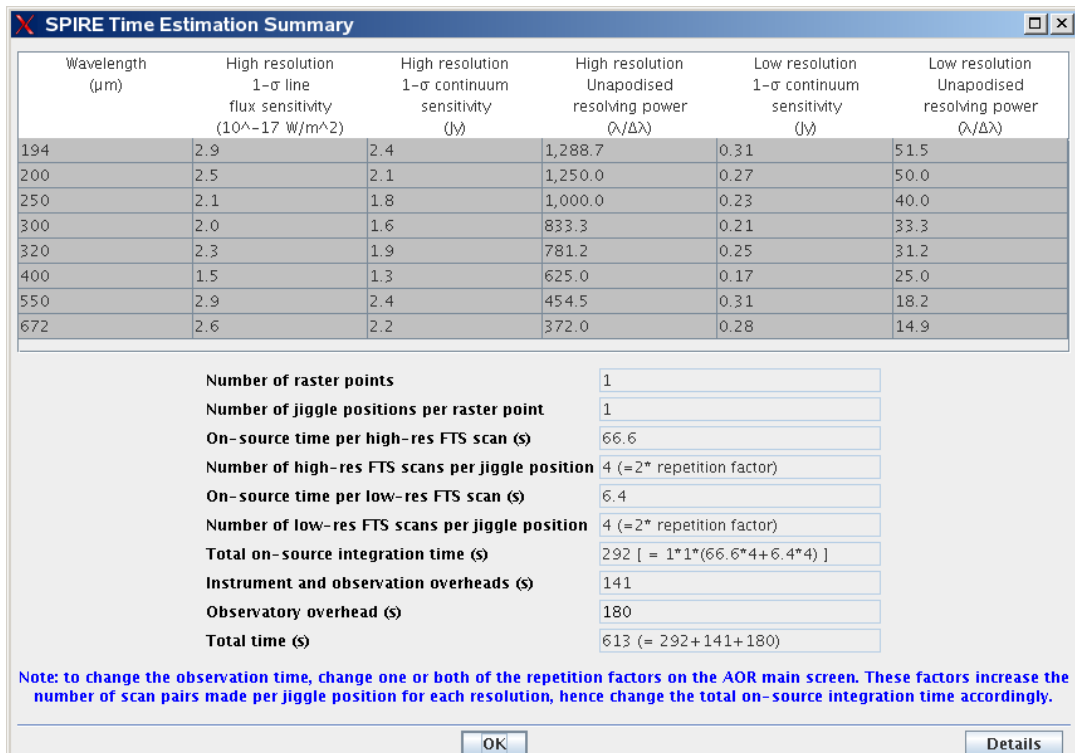
Figure 6.21. Time Estimation Summary for Spectrometer "High and Low" Resolution.

> **Note**
>
> The sensitivity estimates for the "Low" resolution part in the "High+Low" time estimation summary correspond to the low resolution repetitions only. As explained in Section 4.2.1, the high resolution repetitions will be added up to the low resolution ones during the pipeline processing and thus will increase the low resolution sensitivity.

6.5. Time estimation detailed messages

This section describes the time estimation details as reported by HSpot by pressing the "Details" button in the time estimation window (see for example Figure 6.10). The details are complementary to the "Time Estimation Summary". It is possible to select the verbosity level by ticking the relevant "Message level" buttons as shown in Figure 6.22.
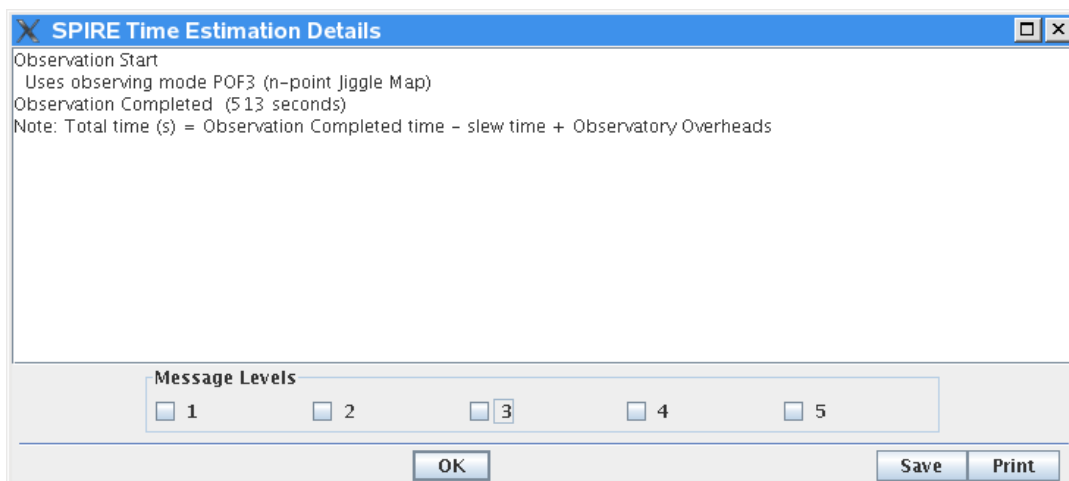
Figure 6.22. Time estimation details initial window.

Because the observing modes for SPIRE have different timelines and instrument commanding so the detailed messages are different. Here we illustrate the different verbosity levels using SPIRE Photometer small map mode. The observer can experiment with the other observing modes in HSpot.

Note that the "Observation Completed" time, shown at the end of the message window, equals the "On-source integration time" + the "Instrument and observation overheads" reported in the "Time Estimation Summary" window + an additional minimum slew time which depends on the observing mode. The slew to add can be retrieved from the messages at verbosity level-3 (see below), the parameter is "tSlewMin" and currently it is 6 seconds for the photometer AOTs and 19 seconds for the spectrometer ones.

For concatenated observations on the same target, which have no "Observatory overheads", then the "Observation completed time" is the "Total time".

6.5.1. No message level selected

This option gives the most basic information as shown in Figure 6.22.

6.5.2. Level-1 messages

Gives a simple breakdown of the total time for each block (detailing initialisation, PCAL flashes, BSM Moving, scanning and reconfiguration). An example is shown below:
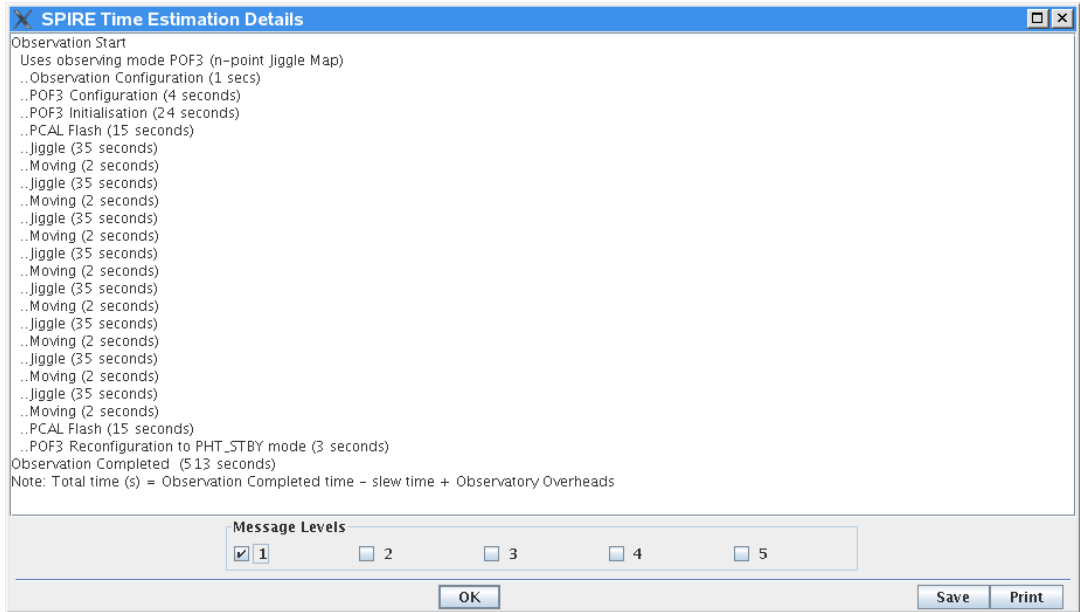
Figure 6.23. Time estimation details, messages level 1.

6.5.3. Level-2 messages

This selection gives a more detailed breakdown with a running counter through the observation in seconds. This running counter, the number inside the square brackets in the example shown below, takes account of all overheads.
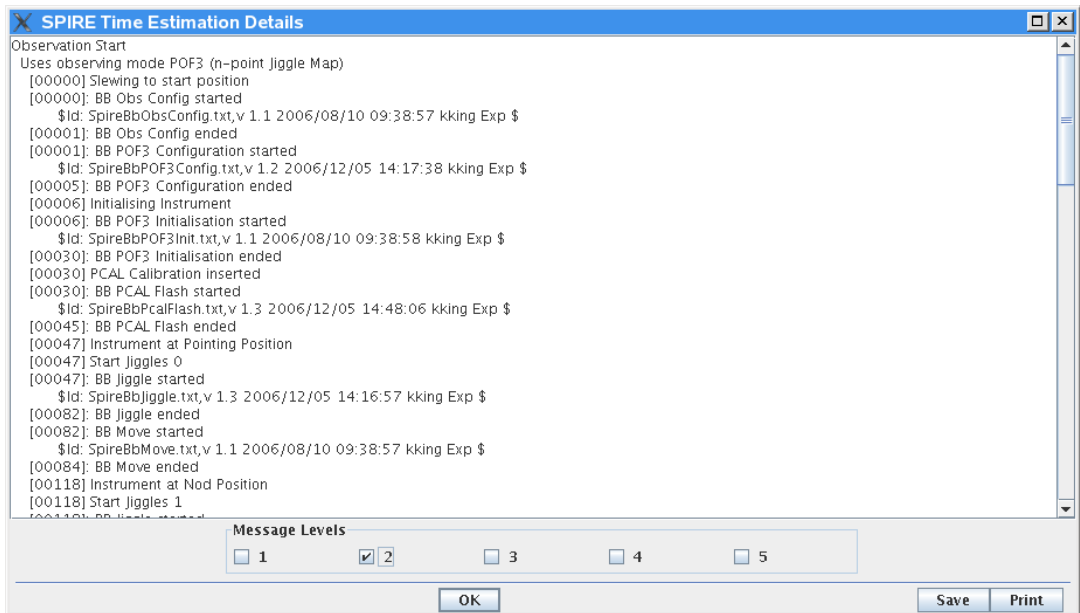
Figure 6.24. Time estimation details, messages level 2.

6.5.4. Message levels 3, 4 and 5

This selection gives even more detailed information about the observation, such as input values to the instrument commanding scripts, fixed values for some observation parameters, detailed list of

individual commands sent to the instrument. An example of level-3 is shown below.
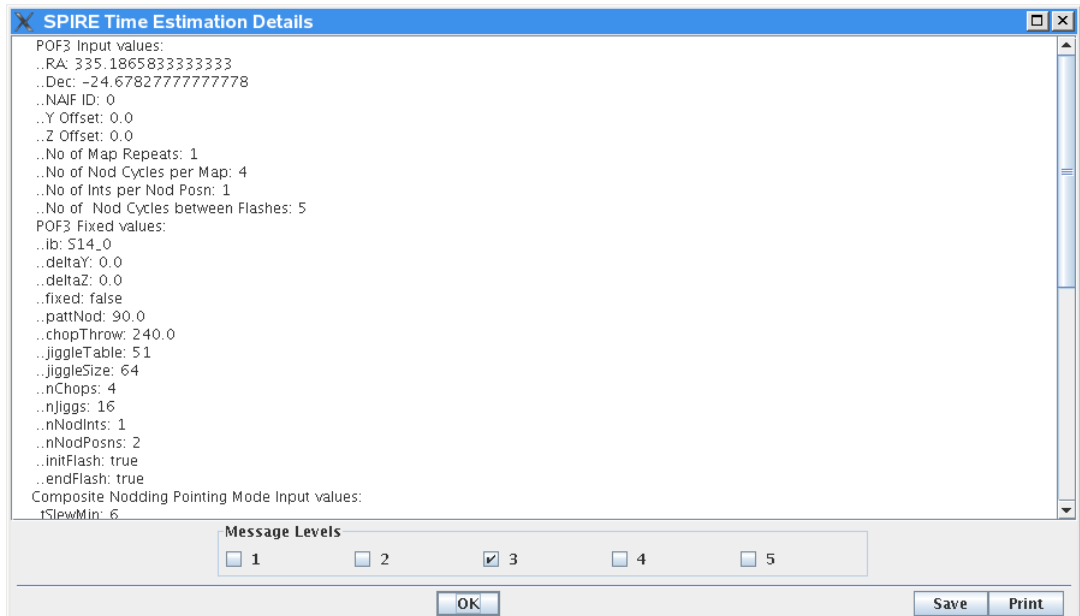
Figure 6.25. Time estimation details, messages level 3.

> **Note**
>
> In general, the information content in the different levels is not the same and it is possible to select multiple levels, for example levels 1+2+3 can be selected, however we advise using levels 1+3.

6.5.5. What additional information from the detailed messages can be used?

It is obvious from the examples shown in the previous sections, that the details messages for levels above two contain a lot of verbose and too technical information. In some cases, however this is the only place where some additional information on the observation can be found. One such example is the minimum slew time which has to be added to the on source integration time and the instrument and observation overheads in order to get the observation complete time. This parameter can be found in level-3 messages as "tSlewMin" under "Pointing Mode Input Values".

For SPIRE Photometer Large Map mode:

- The number of the scan lines in SPIRE Photometer Large Map mode;

- The length of the scan line (longer than requested to make sure requested area is fully sampled);

- The total integration time per scan line.

This information can be retrieved from the level-3 message as shown below for a large map of size 40x20 arcmin, cross-linked scan at nominal scan speed. Note that only the relevant values from the detailed message are shown and for some of them we insert a short description after the "#" sign.

```
        # This is for the first scan direction (Scan angle A)
    POF5 Observing Input values:
```

```
     ..nRepeats: 1
     ..mapWidth: 40.0  # in arcmin
     ..mapHeight: 20.0 # in arcmin
     POF5 Fixed values:
     ..patt: 42.4 # this is the scan angle A in degrees
     ..d2: 348.0 # the distance between successive scan lines, in arcsec
     ..scanRate: 30.0 # in arcsec/s
      Required number of scan lines in map: 4
      Integration time per scan line: 98.7  # in seconds
      Required scan length: 3081.0 # in arcsec
      Total observing time: 412.0  # in seconds
         # This is for the second scan direction (Scan angle B)
     POF5 Observing Input values:
     ..nRepeats: 1
     ..mapWidth: 20.0  # in arcmin
     ..mapHeight: 40.0 # in arcmin
     POF5 Fixed values:
     ..patt: 317.6 # this is the scan angle B in degrees
     ..d2: 348.0 # the distance between successive scan lines, in arcsec
     ..scanRate: 30.0 # in arcsec/s
      Required number of scan lines in map: 8
      Integration time per scan line: 58.7 # in seconds
      Required scan length: 1881.0 # in arcsec, including turnaround
      Total observing time: 504.0 # in seconds
```

From the above information we can see that the 40x20 arcmin large map will have 4 scan lines in one of the scan directions and 8 scan lines in the other. The scan length is 51.35 arcmin for the longer dimension and 31.35 arcmin for the shorter dimension, so overhead of 11.35 arcmin in all cases to make sure the requested area is fully sampled.

For SPIRE Spectrometer raster:

• The number of raster positions and their position in the Y-Z plane relative to the target.

As before, this information can be retrieved from level-3 message as shown below for a spectrometer raster of size 4x6 arcmin, Medium spectral resolution and intermediate spatial sampling. Note that only some relevant values are shown.

```
Spectrometer Raster Observation
Observation Start
  Uses observing mode SOF2_int
    ..Pointing: raster
    ..Sampling: intermediate # spatial sampling
    ..Resolution: M  # spectral resolution - M=medium
    ..mapSize1: 4.0  # in arcmin
    ..mapSize2: 6.0  # in arcmin
    ..nRasters: 1
    ..nPoints: 12 # this is the number of rasters
    ..nMaps: 1
    ..nHCycles: 0
    ..nMCycles: 2 # two scans per raster
    ..nLCycles: 0
    ..Y raster positions:[-202.0244345422332,-119.9619345422332,...]
    ..Z raster positions:[32.64966536032054,114.65091536032054,...]
```

6.6. Example: SPIRE Photometer

Important

In the following examples we assume the reader is familiar with (i) the observing modes for the SPIRE Photometer as explained in Chapter 4 and (ii) with the basic usage of HSpot as explained in the HSpot Users' Guide.

Note

The AOR files for the examples in this section, as well as a fits image for one of the targets (NGC7252) are available in a zip file and can be downloaded from here.

6.6.1. SPIRE Photometer Point Source

To illustrate the steps to follow if you want to propose point source photometry we use one of the most observed and studied extragalactic objects: the quasar 3C 279.

1. Open HSpot and chose "SPIRE Photometer..." astronomical observation template: Figure 6.26.
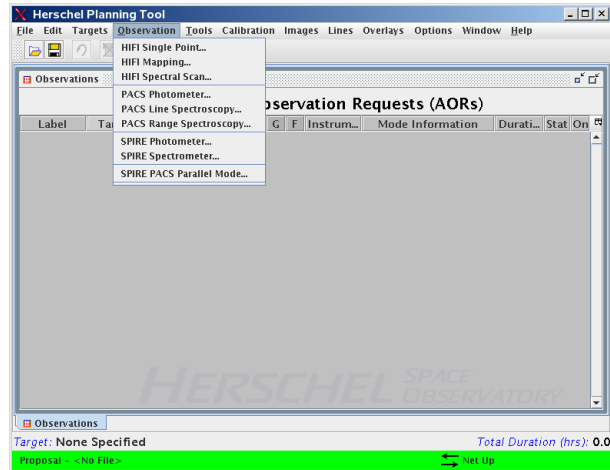
Figure 6.26. The initial HSpot window showing the observing templates of the Herschel instruments.

2. In the SPIRE Photometer window shown in Figure 6.27:
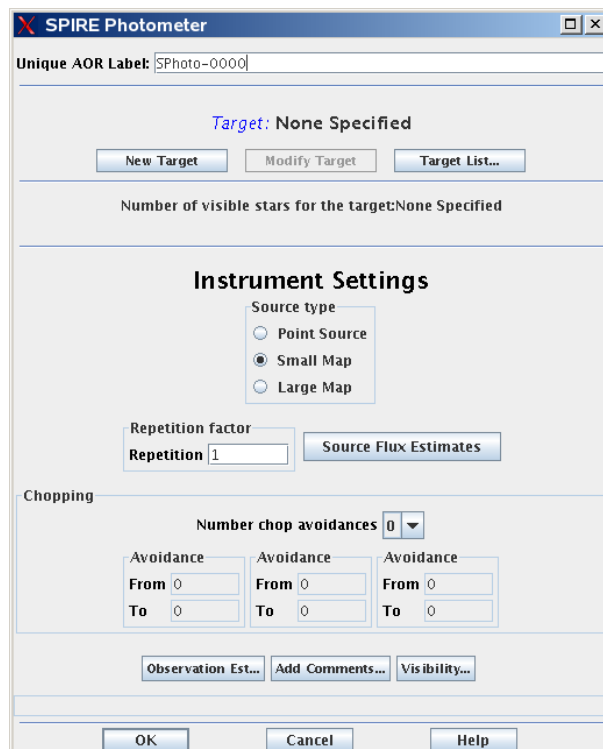
Figure 6.27. The initial SPIRE Photometer window.

a. Rename the AOR label to some relevant name, for example SPhoto-3C279-P.

b. Press the "New Target" button in order to input the target name and coordinates as shown in Figure 6.28. The object coordinates can be obtained with name resolution engines from Simbad[1] or the NASA Extragalactic Database[2]. When there is no particular named object in the available name resolution databases then enter the coordinates yourself and specify a name for the target.

Figure 6.28. Target name and coordinates window.

It is advisable to check the visibility of the target by pressing the "Visibility" button, which brings up the window shown in Figure 6.29. The position angle of the Photometer array for the specified date may also be calculated.

Figure 6.29. Target visibility.

It is also advisable to check the background estimate towards the target. This depends on

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[1]Simbad web page: http://cdsweb.u-strasbg.fr
[2]NED web page: http://nedwww.ipac.caltech.edu

the observing date and can be useful as a reference although the actual date at which the observation will be scheduled is not known. The background reference wavelength must be chosen before the estimation is done as shown in Figure 6.30. The result for 07 July 2009 and at 200 μm is shown in Figure 6.31.
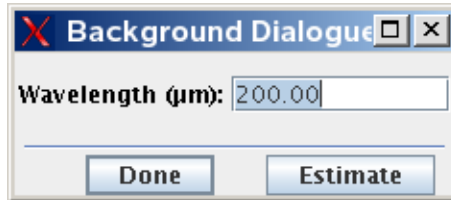
Figure 6.30. Background wavelength dialogue.
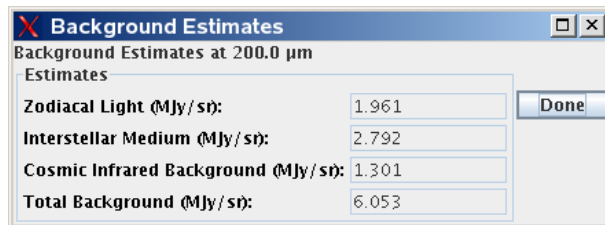
Figure 6.31. Background estimation for 07 July 2009 at 200 μm.

c. Exit the target window by pressing the "OK" button.

d. In the initial SPIRE Photometer screen (Figure 6.27) choose source type: Point Source. This can be done before entering the New Target dialogue.

The result of the above inputs are shown in Figure 6.32. The target coordinates and name should appear as well as an information about the available stars for the star tracker (see Herschel Observers' Manual).
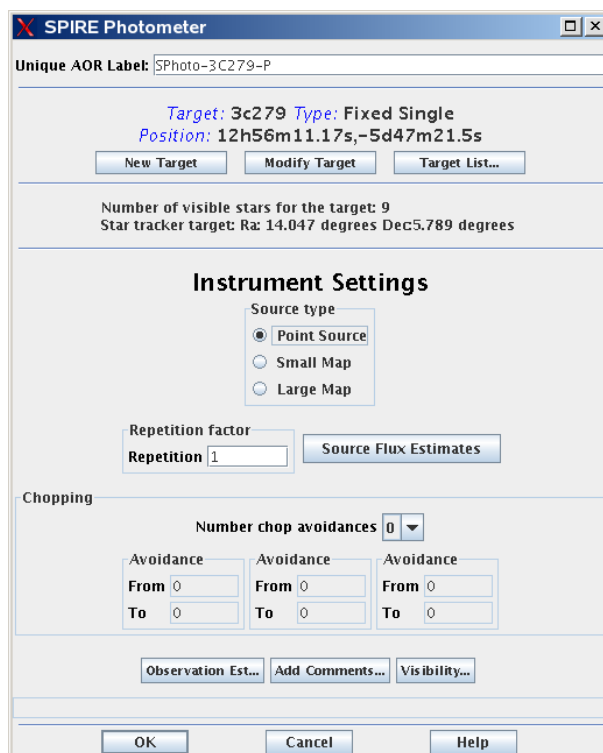
Figure 6.32. The SPIRE Photometer window after target input.

3. If the source flux in any of the SPIRE photometer bands is available the observer can enter it by clicking on "Source Flux Estimate" button which brings up the window shown in Figure 6.33. The example object 3C 279 has already been observed at 350 µm (Hartman et al. 1996) and we have put the flux density of 4100 mJy. This is optional and only helps to get an estimate of the signal-to-noise for the chosen observing parameters. But note that the maximal achievable signal-to-noise ratio is 200 (see Section 3.1.1).
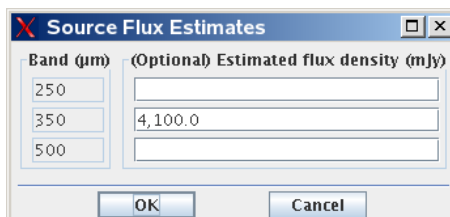
Figure 6.33. Input source flux window.

4. The observation estimate result for 3C 279 is shown in Figure 6.34. Here we used the knowledge of the source flux at 350 µm. Without it we can only get the noise 1-σ levels and no signal-to-noise ratios, as is the case for the other two SPIRE Photometer bands at 250 and 500 µm. Note that the maximum achievable signal-to-noise value of 200 is returned.

Figure 6.34. Observation time estimation.

A detailed breakdown of the time at different verbosity levels can be obtained by pressing the "Details" button on the SPIRE Time Estimation Summary window. The result for level-1 messages is shown in Figure 6.35. More details on the observation parameters can be obtained at higher message levels. Press "OK" to dismiss the this window and return to the time estimation summary.
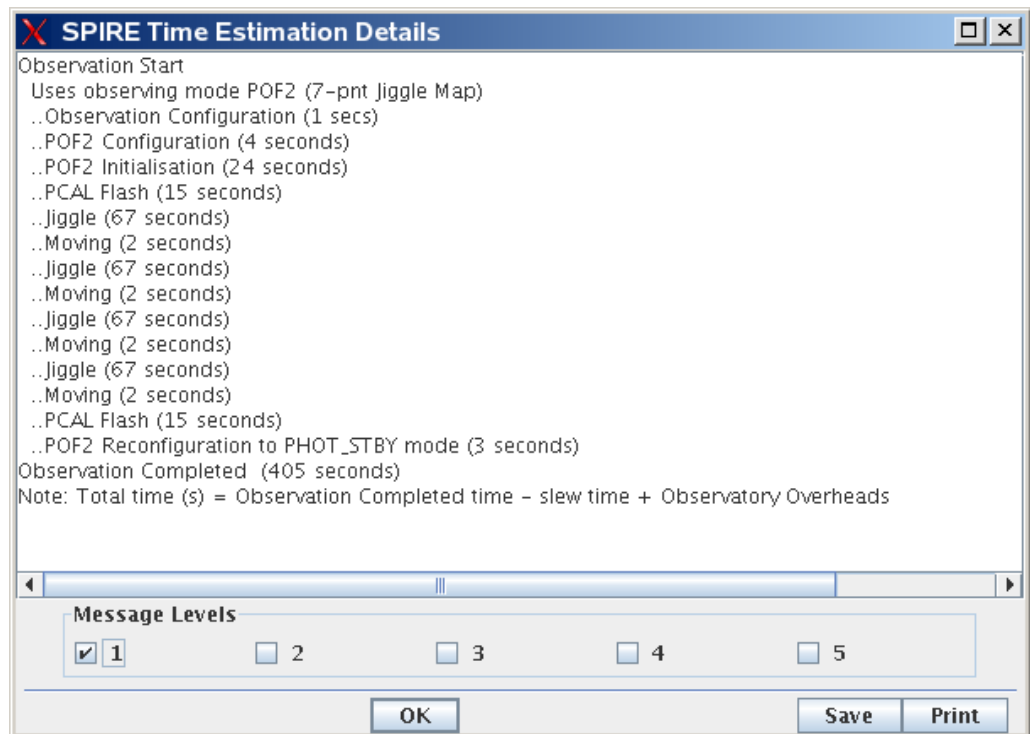
Figure 6.35. Observation time estimation details for level-1 messages.

5. Once the time estimation is acknowledged (by clicking on the "OK" button) then the observing request (AOR) is ready and we can save it in a file either from the pulldown menu under "File" or by pressing the diskette symbol. You should use some relevant name for the AOR and the extension can be anything but we advise you to use .aor. Note that the created file is an XML format file and contains all of the needed information for the observation.

6. It is advisable to visualise the AOR on an already existing image. Most of the available astronomical image servers can be accessed to download an image in a relevant waveband. The access is shown in Figure 6.36.
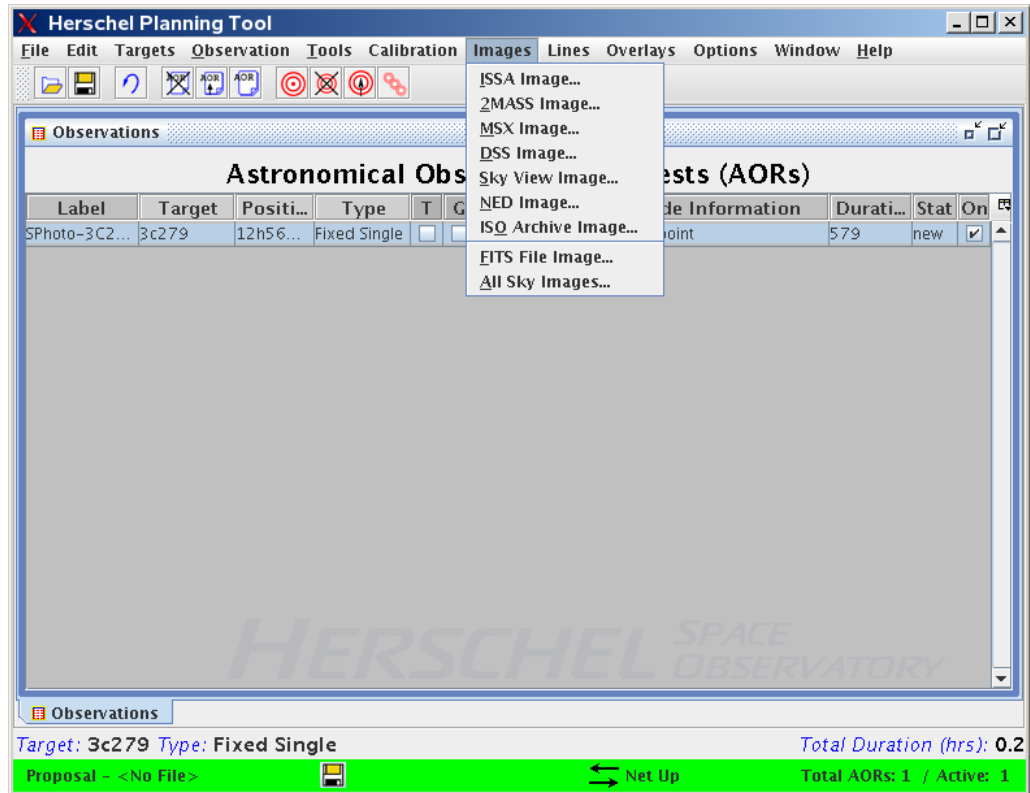
Figure 6.36. Access to archive images menu.

a. Choose an image server. As an example we download a DSS image (HST Phase 2 target positioning - GSC 2) as shown in Figure 6.37.

Figure 6.37. Downloading a DSS image.

The resulting image is shown in Figure 6.38 as well as the menu of the available overlay options.
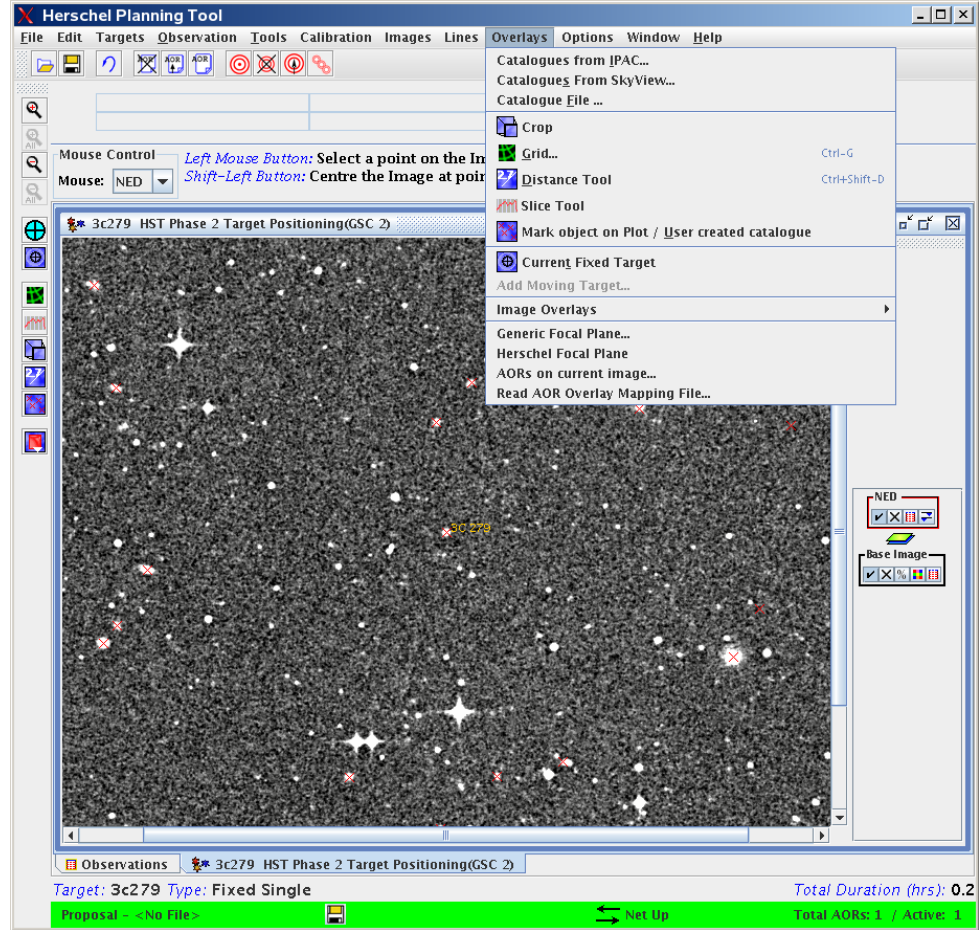
Figure 6.38. The DSS image and the Overlay menu options.

b. We may overlay catalogues of objects on the image. An example is shown from the IPAC (NED) catalogues. The catalogue options are shown in Figure 6.39.
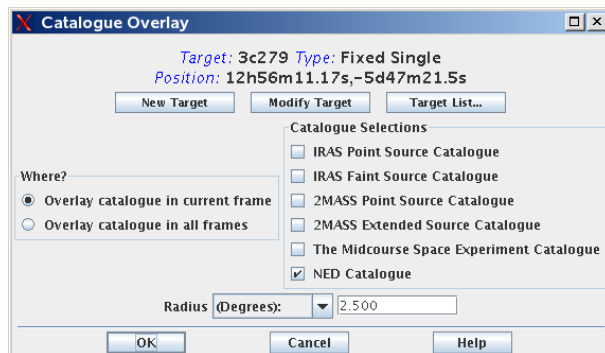
Figure 6.39. The IPAC catalogue window.

Once the catalogue is downloaded, the objects in the catalogue are marked in the image as shown in Figure 6.40. Access to the downloaded and visualised catalogue is through the "Catalog Table" button in the NED box on the right of the HSpot window (the third button is the catalogue table, use the mouse to point above the buttons to see the tooltip). The catalogue options are shown in Figure 6.40 and the user may select/de-select objects to be put on the image, to place the object name (as we have done for 3C 279 in Figure 6.38), choose the symbols, colours etc.
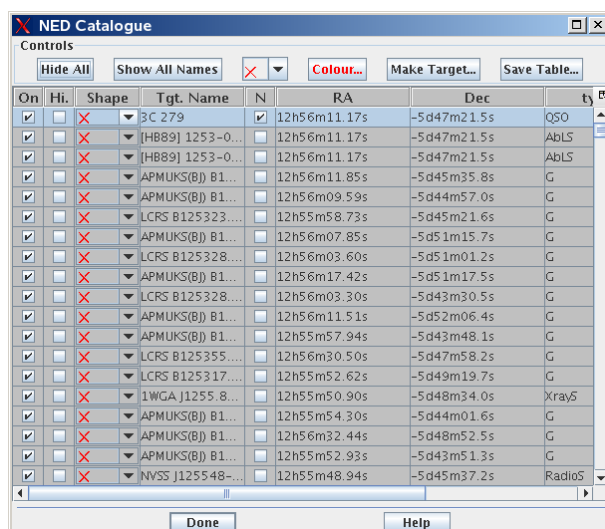
Figure 6.40. The catalogue options window. Note the "N" column and the ticked box for 3C279 - this will label the object on the image.

c.   In order to overlay the observing request we need go to the "Overlays" menu and select "AORs on images...", then if you have defined more than one AOR a pop-up will appear, select "Current AOR". In the following pop-up we have to chose the observation date as shown in Figure 6.41.
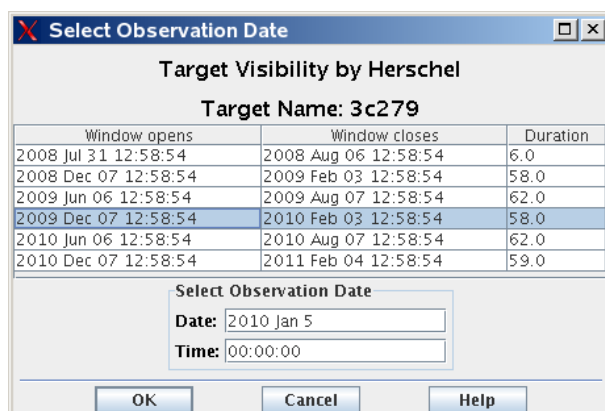
Figure 6.41. The window to select the observing date.

We use the created AOR as an overlay and the result is shown in Figure 6.42. The blue circles, with size corresponding to the FWHM of the beam of the 500 μm band Photometer array, indicate the chopping pixels for the two nod positions of the Photometer (shown as green rectangles). See Chapter 4 for details.
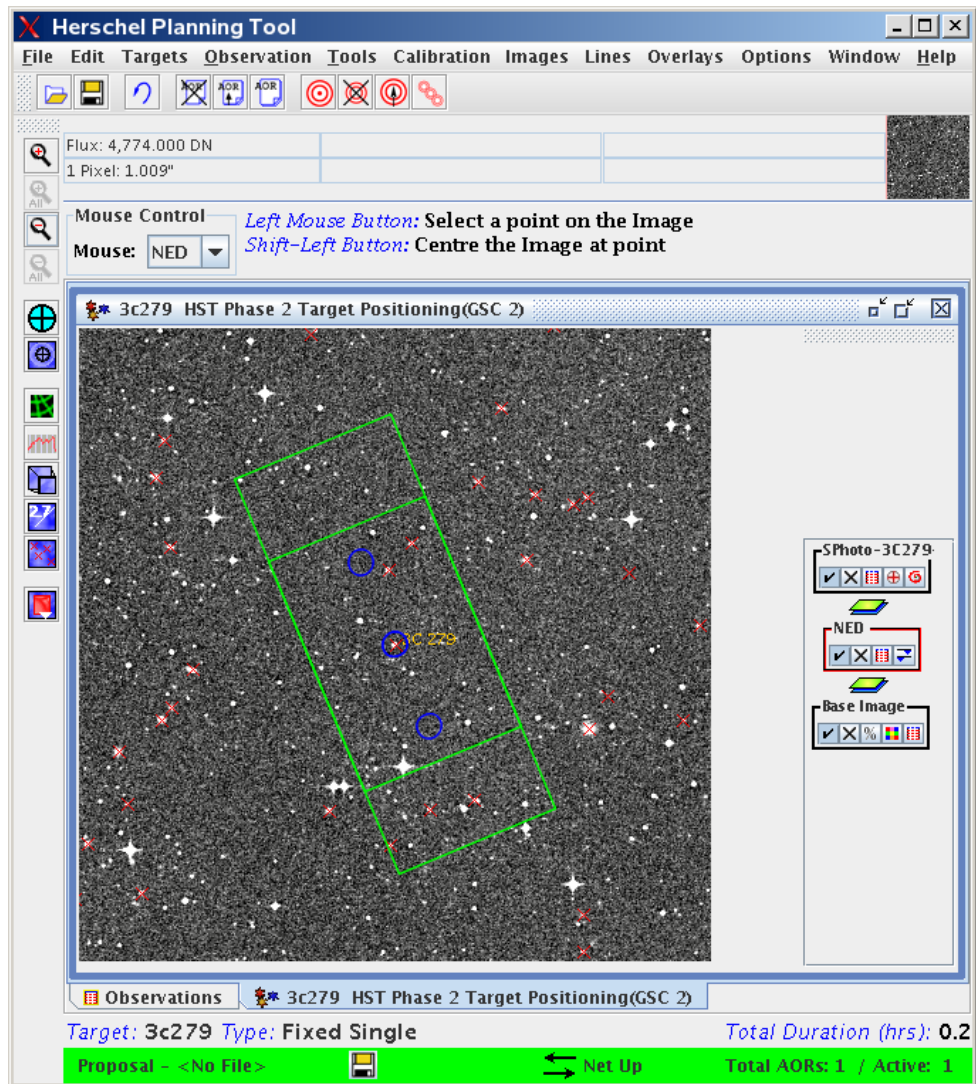
Figure 6.42. SPIRE Photometer Point Source AOR overlaid on a DSS image.

6.6.2. SPIRE Photometer Point Source With Chop Avoidance Angle

Warning

There is currently no indication in HSpot of any reduction of the visibility window caused by choosing to constrain observations. Neither there is an indication in the overlay window. That is why it is advisable to follow the steps below in order to have an idea of how to assess the visibility change and the behaviour of the position angle (i.e. the chopping angles) at different dates of the visibility.

If the chopping (that is, any of the three blue circles in Figure 6.42) happens to fall on a bright nearby point-like or extended source then the correct background subtraction cannot be done. Then

it will be necessary to avoid chopping over certain directions.

The procedure is the same as the Section 6.6.1 example except an additional step before Step 5, which is to enter the number of chop avoidances (up to 3) and give the respective avoidance angles. Selecting one or more chop avoidance angles issues the warning message shown in Figure 6.43.
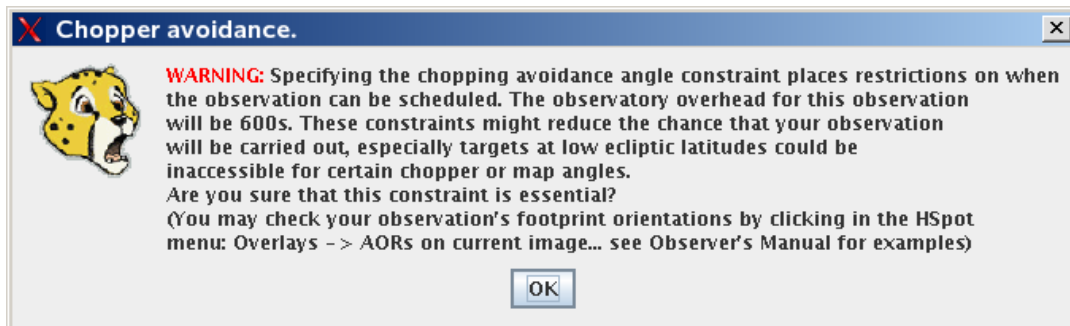
Figure 6.43. Warning message when one or more chop avoidance angles are requested.

To illustrate the way to proceed with chop avoidance angles we shall use M82 - a luminous starburst galaxy. We use point-source photometry as we are interested only on the core of the galaxy.

The position angle of M82 is ~65 deg East of North and we want to avoid chopping on the galaxy itself. This means we want to avoid chopping at angles from 30 to 110 deg (east of north) which, following the discussion in Section 4.1.1 means we have to avoid days when the position angle of the Herschel focal plane is between 120 and 200 deg and also between 300 and 20 deg.

The filled avoidance angles "From angle" of 30 and "To angle" of 110 (east of north) are shown in Figure 6.44.
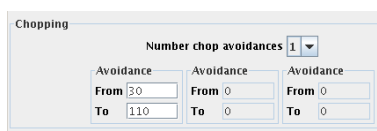
Figure 6.44. Chop avoidance angles filled in.

We follow the example in the previous sub-section from Step 6 and visualise the AOR on a DSS image.

1. Visualise the AOR for the first day of a visibility window: from the "Overlays" pulldown menu choose "AORs on image..." (select "Current AOR" if the "Which AORs" panel pops-up) and select for example 2009 Feb 25 by typing it into the "Date" box.

2. Visualise the same AOR for the last day of the same visibility window, which in this case is 2009 Jun 13 by following the previous step: i.e. from the "Overlays" pulldown menu choose again "AORs on image..." and type in the corresponding date.

   The result should look like Figure 6.45.
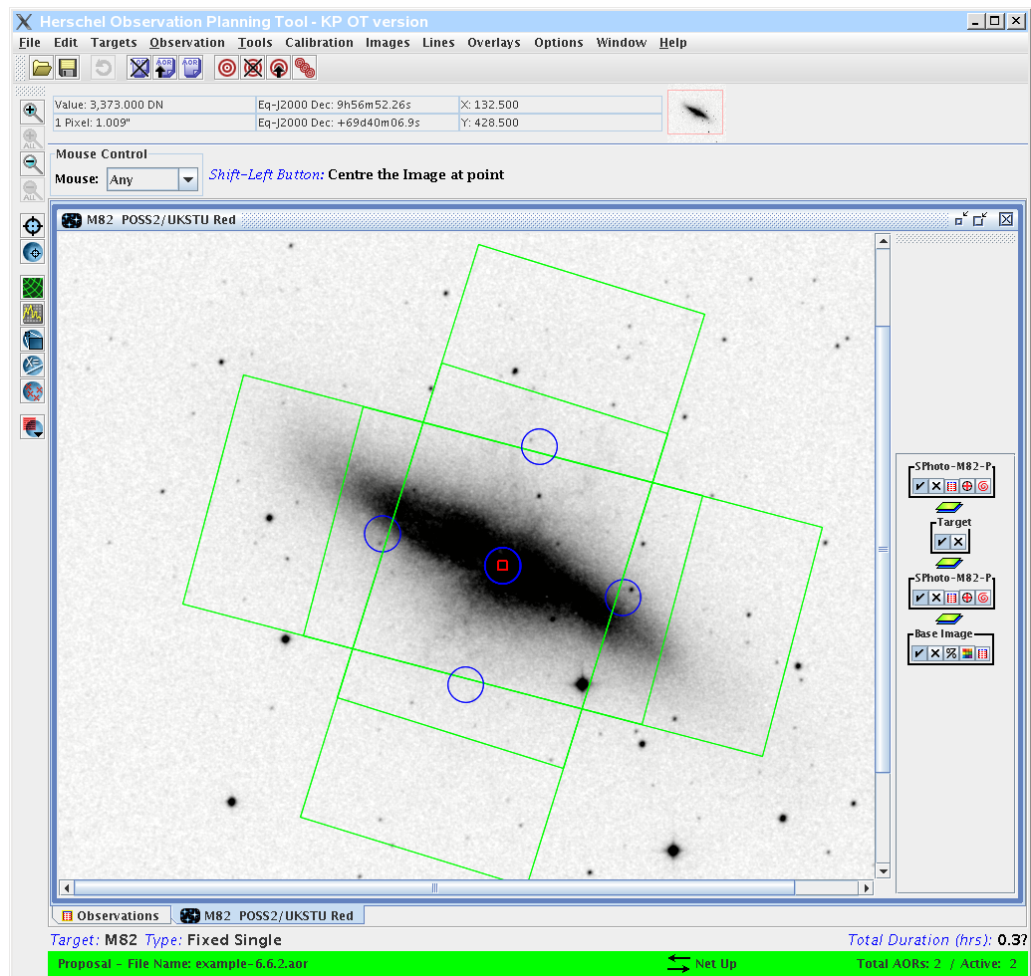
Figure 6.45. AORs for two extreme visibility dates for M82. Note that the grey-scale colour table was inverted to show better the overlay (see HSpot User's Guide).

3. Take note of the Herschel Position Angle for each of these two dates.

We do this by clicking on the pointing table which is the 3rd button from left to right in the "SPhoto-M82-P" (the first characters of the AOR label) box on the right of the image. The buttons have tags so you can identify which one it is by pointing with the mouse. We show the pointing table in Figure 6.46. The position angle of the Herschel focal plane, as well as the corresponding date for which the AOR was overlaid, are both shown at the bottom of the "Pointings Table" window.
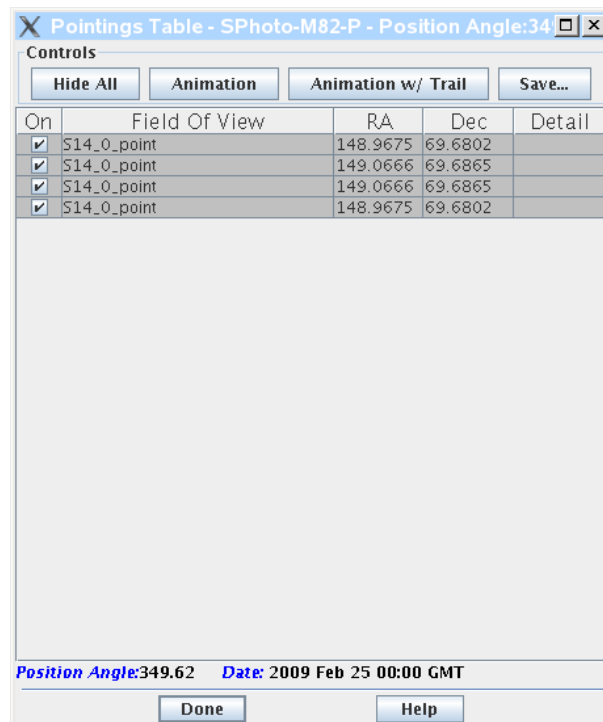
Figure 6.46. Pointing table as appears after pressing the "Pointing Table" button.

We repeat the same for the second AOR (last day of visibility) and we get the two position angles: 350 deg and 257 deg respectively. Note that for the next visibility window they will be at ~ 180 degrees to these, i.e. 77 deg and 172 deg for the first and last days of visibility.

4. Replot the AOR for different dates until you find the dates when the position angle of the Herschel focal plane is 300 deg - on 2009 Apr 23.

    We do this by pressing on the last button in the "SPhoto-M82-P" box (when you point the mouse over it it will show a tag "Replot AOR at different Date"). This will bring up a visibility window like in Figure 6.41. Choose a day between 2009 Feb 24 and 2009 Jun 13.

    After some trials we find that from 2009 Feb 25 to 2009 Apr 23 the position angle is inside our exclusion zone: from 300 to 20 deg. Which means the observation will not be scheduled in these 58 days from the total of 109 days in the visibility window.

5. Choose a date outside the constrained period to make sure that indeed the chopping is outside the galaxy. The result for 2009 May 20 is shown in Figure 6.47.
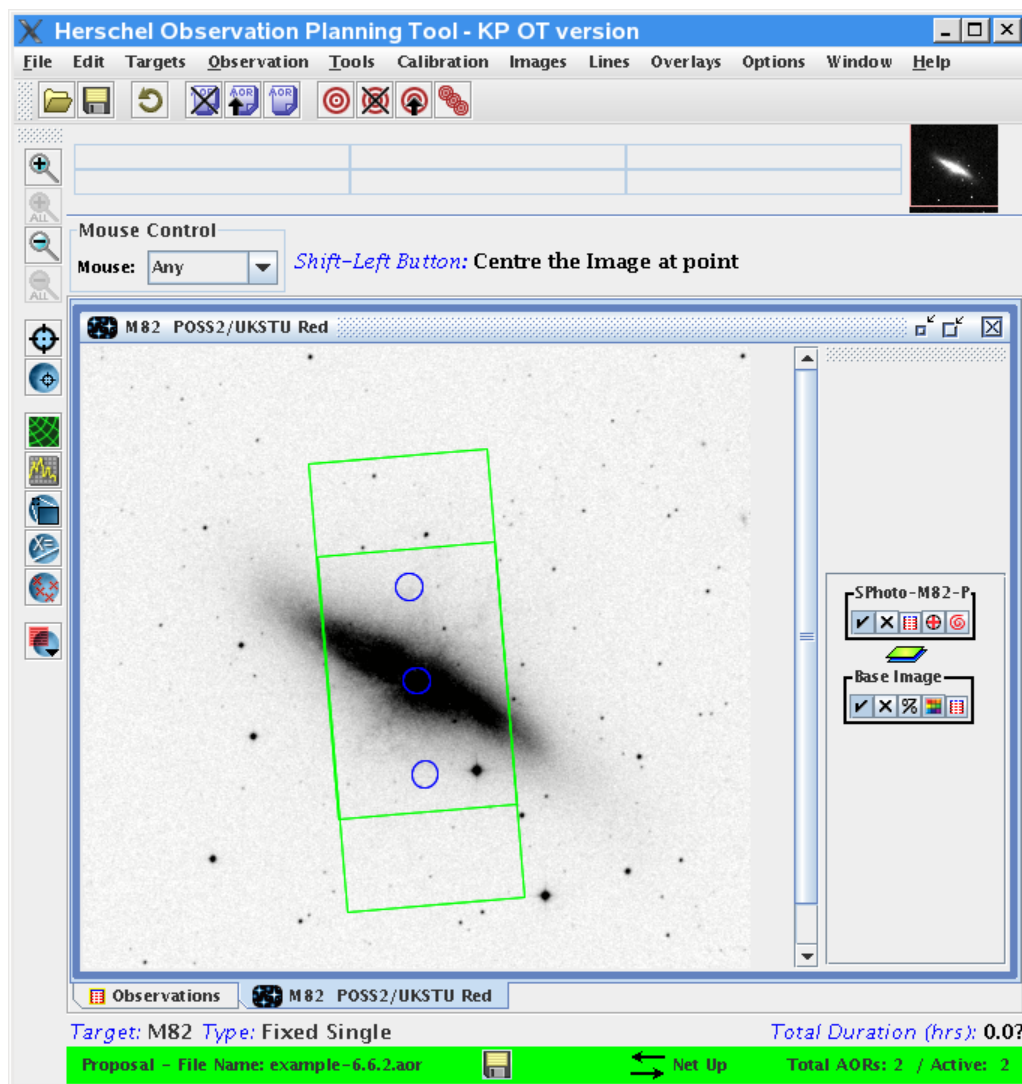
Figure 6.47. SPIRE Point source photometry AOR shown for a date outside the chop avoidance period.

Let's now define an example with NGC 7252 where we have changed the target, not to be the galaxy itself, but a point some ~1 arcmin away (RA=22:20:39.04, Dec=-24:38:28.2). When we overlay the AOR on a DSS image for example, we see that one of the chopped pixels falls on the bright galaxy and will hamper the background subtraction - Figure 6.48. So we need to avoid this chopping direction (~150 deg east of north or ~330 deg modulus 180 deg). These two chop avoidance angles correspond to focal plane position angles of 240 deg and 60 deg. If we overlay the AOR for the first and the last day in a visibility window as shown in Figure 6.48, we can see that the position angle changes from 240 deg at the beginning to 256 deg at the end. For the next visibility window these angles will be at 180 deg (so 60 and 76 deg respectively). Unfortunately this is the range we want to avoid. So, because of the unfortunate location of the target (at ecliptic latitude of -13.3 deg) if we set "Angle From" to 150 deg and "Angle To" to 165 deg then this observation will never be scheduled because the position angle is always inside these limits. That is why it is advisable to check the visibility of all constrained observations by overlaying the AORs for the limits of each visibility window.
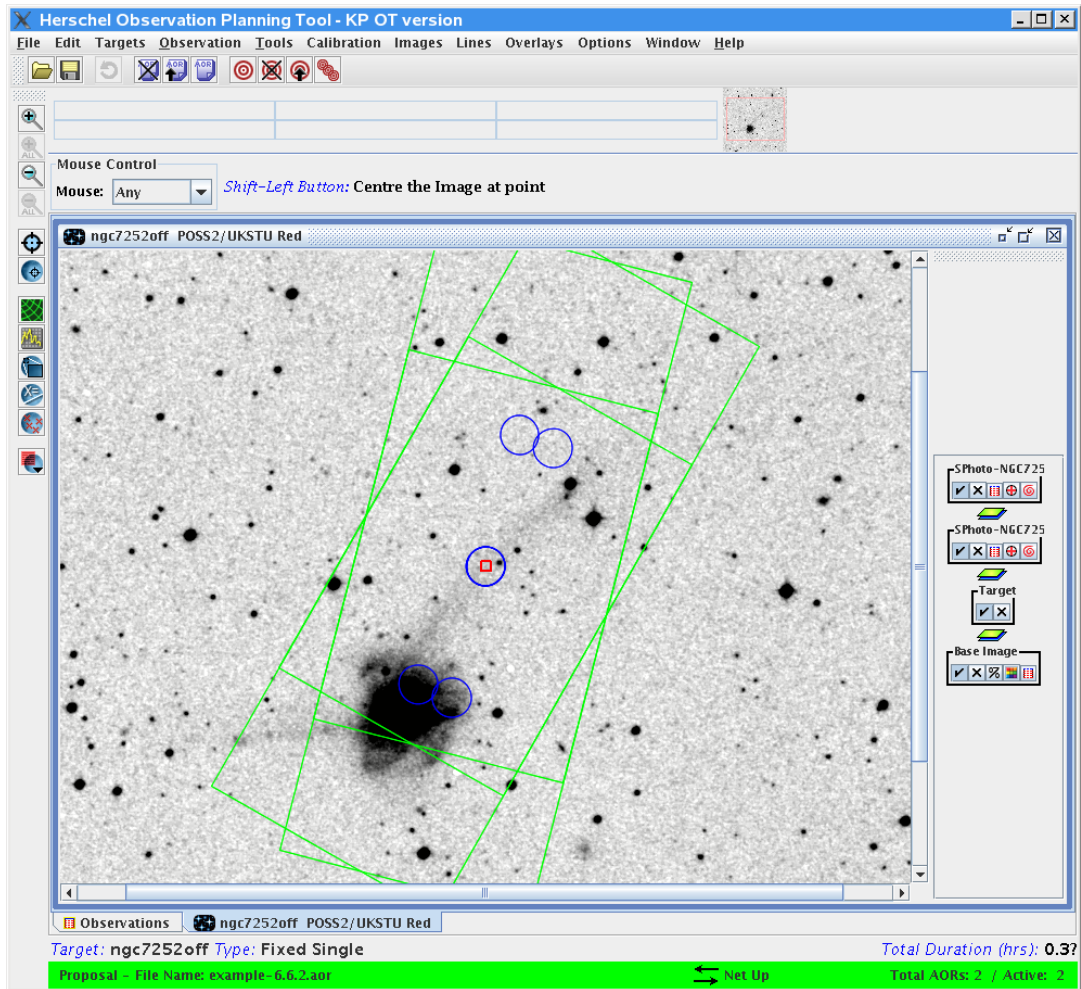
Figure 6.48. SPIRE Photometer Point Source photometry with chopping on a bright galaxy. The target is the red box. Note that the grey-scale colour table was inverted to show better the overlay.

6.6.3. SPIRE Photometer Small Map

To illustrate the steps to follow when the observer wants to propose an observation of a region of size about 4 arcmin diameter we use NGC 7252 - a luminous interacting infrared galaxy.

1. The steps are exactly the same as the Section 6.6.1 example except that before Step 5 we must choose source type "Small Map" as shown in Figure 6.49. Note that this mode is selected by default whenever a new SPIRE Photometer AOT is open.

Figure 6.49. SPIRE Photometer initial screen with the AOR name, target coordinates and name already entered and the instrument source chosen as Small Map.

2. Entering the source flux estimate: the galaxy is not observed at wavelengths similar to the SPIRE ones. From the available IRAS observations at 100 µm and the overall shape of the galaxy spectral energy distribution (i.e. using NED photometry and SED tool) we may infer a flux of 6 Jy at 250 µm. Note that as before this step is optional and perhaps is more relevant for fainter sources when the signal-to-noise is critical. The entered value is shown in Figure 6.50. Note that in the case of Small Map an estimation of the surface brightness in MJy/sr (for example for an extended sources) may be put as well.

Figure 6.50. Flux estimation for the SPIRE Photometer small map.

From this flux estimate we may proceed further and obtain the observation time estimate,

shown in Figure 6.51 and the corresponding observing time breakdown details in Figure 6.52. If the resulting 1-σ noise level is too high or the signal-to-noise ratio too low, then the observer can increase the repetition factor. This is done by pressing the "OK" button and going back to the AOT main window and increasing the repetition factor. Then a new time estimation can be done by pressing the "Observation Est...". Increasing the repetition factor of course results in longer observing time as shown in the time estimation for the same example but with repetition factor of 2: Figure 6.53.

SPIRE Time Estimation Summary

Band (μm)	Point Source Flux Density (mJy)	Point Source S/N	Point Source 1-σ noise (mJy)	Extended S... Surface Brightness (MJy/sr)	Extended S... S/N	Extended S... 1-σ noise (MJy/sr)
250	6,000.0	200.0	4.7			1.05
350			6.3			0.74
500			5.3			0.30

On-source time per repetition (s)	256
Number of repetitions	1
Total on-source integration time (s)	256 (=1*256)
Instrument and observation overheads (s)	251
Observatory overhead (s)	180
Total time (s)	687 (=256+251+180)

Note: to change the observation time, change the repetition factor on the AOR main screen. It multiplies the on-source integration time per repetition to give the total on-source time.

Confusion noise estimation summary

Band (um)	Est. 1-σ Confusion Noise Level for Point Sources (mJy)	Est. 1-σ Confusion Noise Level for Extended Sources (MJy/sr)	Est. 1-σ Confusion Noise Level per Pixel (mJy)
250	4.6	0.8582	5.1
350	5.6	0.4827	5.9
500	4.5	0.2091	4.9

Update Confusion Noise Estimation   Confusion Noise Estimator Messages

OK   Details

Figure 6.51. Time estimation for the SPIRE Photometer small map.
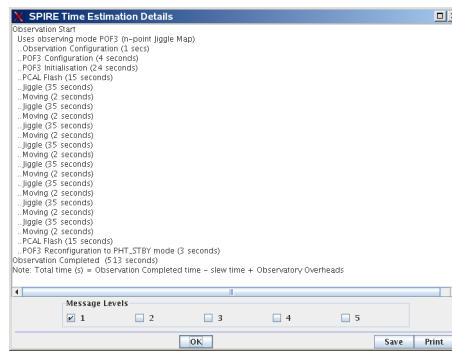
Figure 6.52. Time estimate breakdown.

Figure 6.53. Time estimation for the SPIRE Photometer small map. Repetition factor is 2.

3. To visualise the AOR on an image we use a user supplied FITS file. This is possible from the "Images" pulldown menu (see Figure 6.36) and if the user selects "FITS File Image..." then a window with the filesystem is brought up and it is necessary to find and select the fits file to load. This is shown in Figure 6.54. The file extensions which can be used are "*.fits" and "*.fits.gz" (gzip compressed fits file). We use an optical image from the CTIO 4-m telescope in B-band. The image with the small map AOR overlay is shown in Figure 6.55.
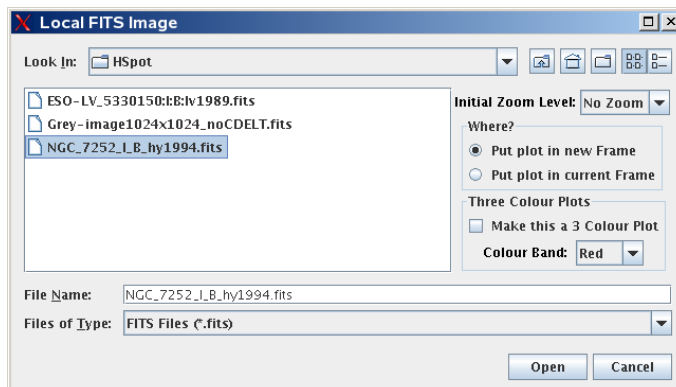
Figure 6.54. FITS file read dialogue window.
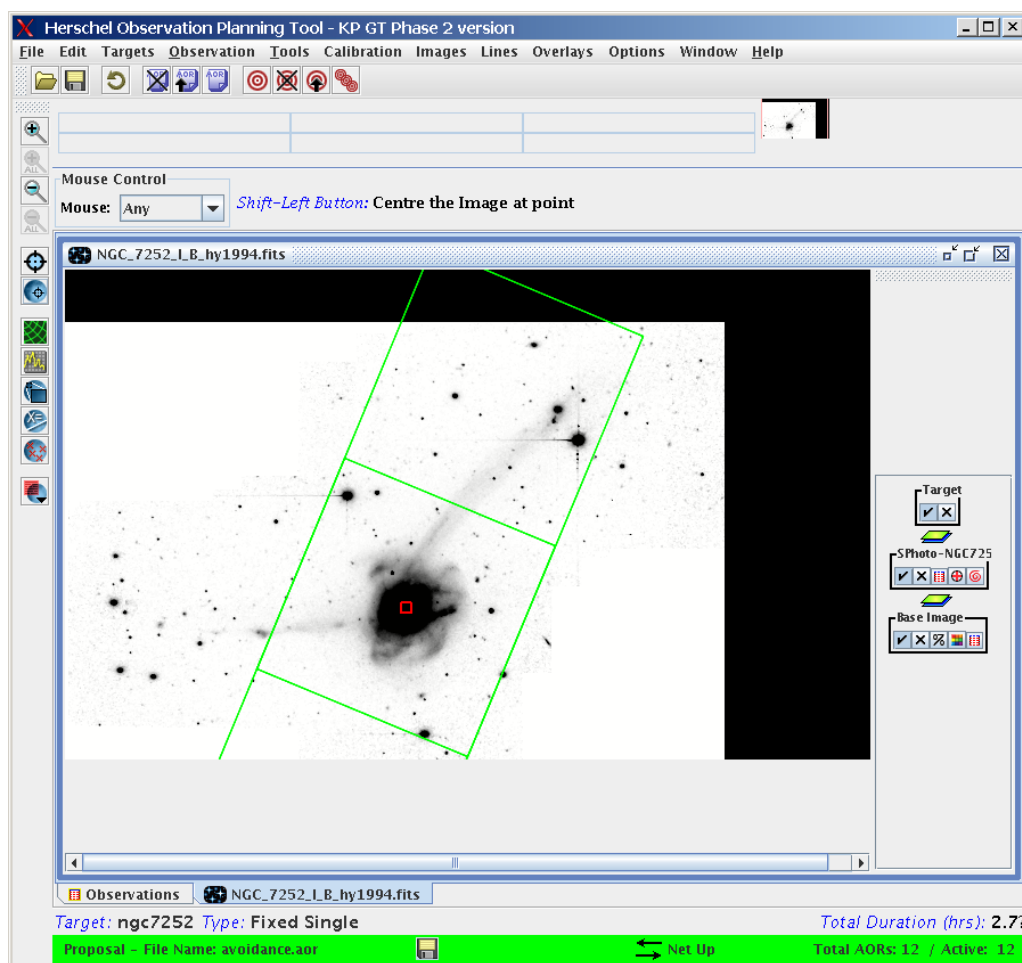
Figure 6.55. SPIRE Photometer small map AOR overlay on an optical B-band image from the CTIO. The map centre is indicated by the red box. Note that the grey-scale colour table was inverted to show better the overlay.

The same procedure as in the previous example can be followed when the chopping of the small map mode falls on a bright source or a region with high background. That is, 1) choose the chop avoidance angles, 2) convert them to pairs of Herschel focal plane position angles, 3) using the target visibility tool or the AOR overlay, identify the days in a visibility window when the position angle is inside the avoidance range and finally estimate the total number of days in a given visibility window when the observation can be scheduled. As in all cases of constrained observations, the observer will be charged 10 minutes overhead time (see the warning message shown in Figure 6.43).

6.6.4. SPIRE Photometer Large Map

To illustrate the steps to follow when the observer wants to propose an observation of a large region, larger than 4 arcmin diameter which can be done with the Small Map observation, we use one famous extragalactic field: The Lockman Hole and we select a region of 40x20 arcmin centred on the XMM field centre (RA=10:52:40.60, Dec=+57:28:29.0).

> **Warning**
>
> We give an example for Large Map AOT with the default option to perform a cross-linked map of the region, that is first scan at angle A and then scan at angle B (see Section 4.1.3). In this case, if the selected area is rectangular it does not make any difference on the total time which dimension on the map is the larger. If you choose however a single scan direction, like in the next example, then it does make difference if you chose the scan leg length to be the larger dimension.

Procedure 6.4. Cross-linked large map example

1. Please follow Step 1 to Step 4 from Section 6.6.1 example to enter the target information.

2. Select the Source Type as "Large Map" and enter the desired dimensions of the map, namely 40x20 arcmin, as shown in Figure 6.56.

Figure 6.56. SPIRE Photometer initial screen with the AOR name, target coordinates and name already entered and the instrument source chosen as Large Map. Note that the map dimensions (40x20 arcmin) have been entered and the default options for scan direction and scan speed, namely "Scan Angles A and B" and "Nominal", are used.

3. Entering the source flux estimate. In case when there is no particular source we may enter a desired fiducial flux so that to estimate the signal-to-noise for sources close to this limit. We chose a limit of 100 mJy at 250 µm. If we are going to map an extended object we may give the surface brightness estimation in MJy per steradian as well. An example of user input is shown in Figure 6.57.

Figure 6.57. Input fluxes for the target.

The observation time estimation is shown in Figure 6.58 and the detailed breakdown of the

time in Figure 6.59.
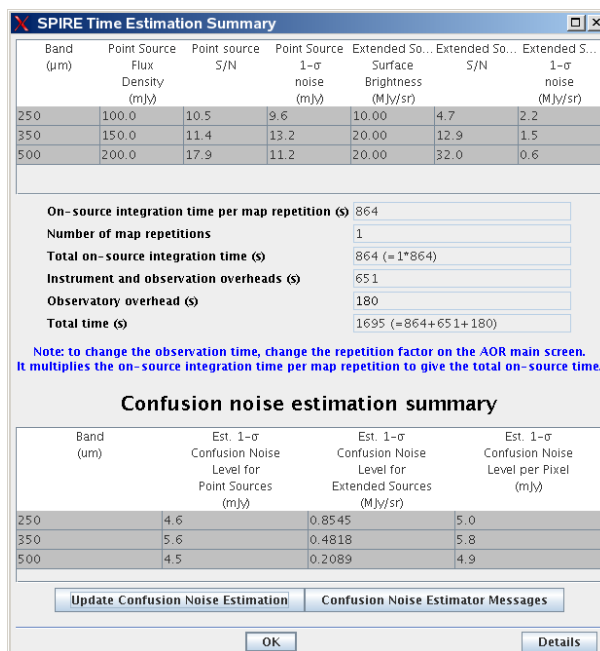
Figure 6.58. Time estimation for large map observation. The repetition factor is 1.
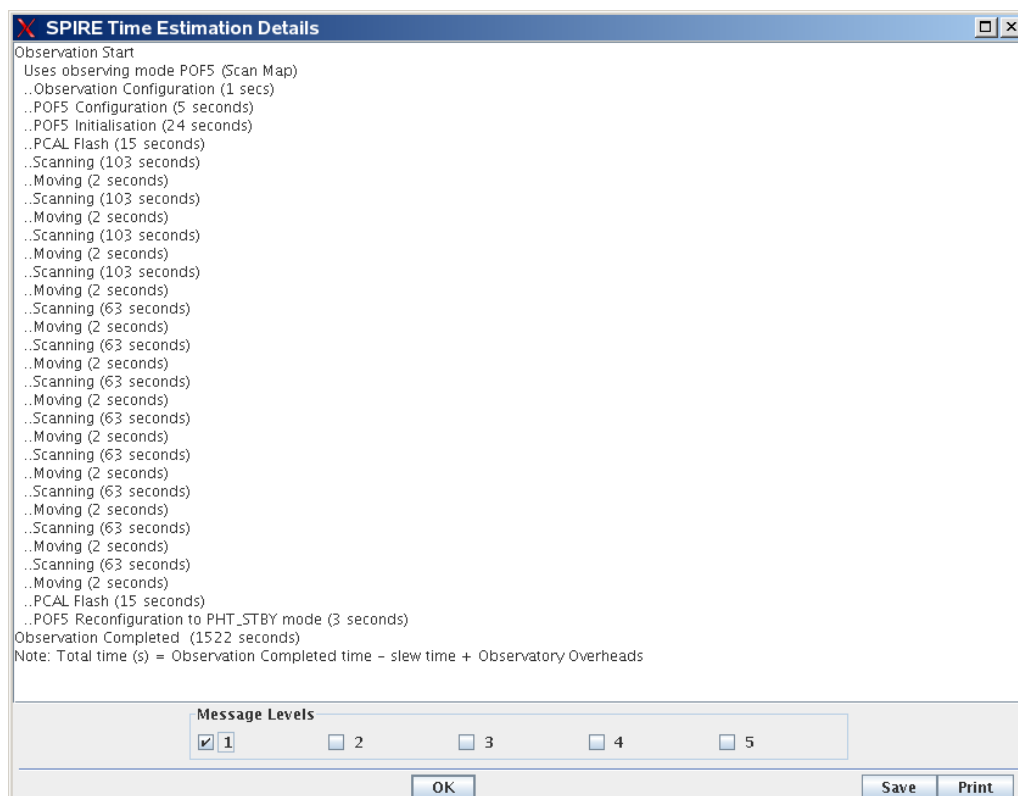
Figure 6.59. Time estimation breakdown for large map observation.

If necessary, i.e. the SNR is not satisfactory, then we can increase the repetition factor (see Figure 6.56). The resulting observation time estimation, with repetition factor of three is shown in Figure 6.60.

Figure 6.60. Time estimation for large map observation. The repetition factor is 3.

4. To visualise the AOR on an image we use IRAS 100 μm image, following Step 6 from Section 6.6.1 example. The IRAS image with the large 40x20 arcmin map AOR overlay is shown in Figure 6.61. The map centre can be displayed from the "Overlays" pulldown menu choosing "Current Fixed Target" option (also available as a shortcut button, sixth from top on the left of the image, tooltip "Draw current target on images"). The map orientation is given for the middle of the visibility window (08 May 2010 in this particular case).

> **Note**
>
> The visualisation shows the total length of the scan legs and the total number of scans which are used to make sure that the user requested area is covered uniformly.
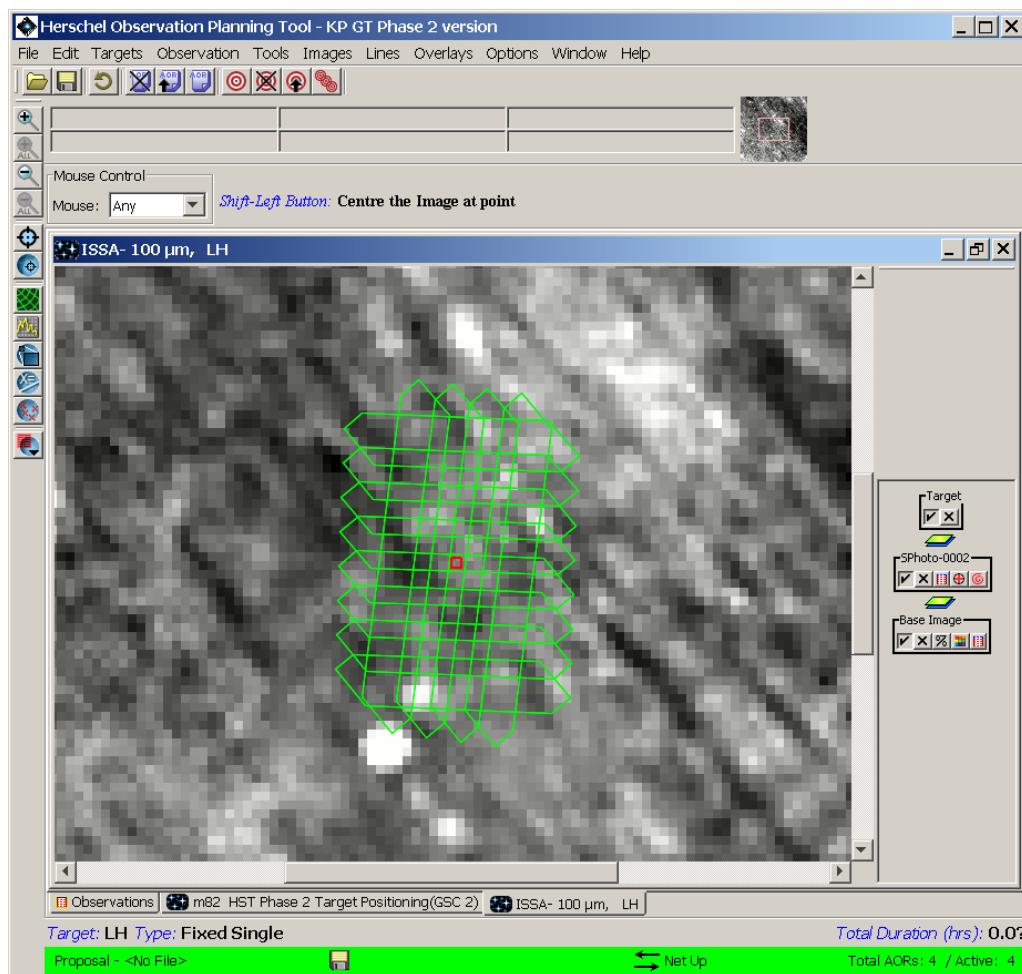
Figure 6.61. Large map AOR overlay on the 100 μm IRAS image downloaded from ISSA.

6.6.5. SPIRE Photometer large map with map centre offset

This example shows a case when the observer wants to map a region with the target not in the centre, even it can be outside the map itself. One example can be to map an infrared emitting cloud or for example a cluster of galaxies when only the radial distribution in a narrow region is the goal. The azimuthal orientation of the scan map is not important but the pivot point. The map centre offset is given in detector Y and Z coordinates which complicates somewhat the initial setting of the offsets.

Here we show one example on how to do this using single scan angle - "Scan Angle A" at nominal scan speed of 30"/s. The example is shown for the Lockman Hole observation for visibility window in Sep-Dec 2008 and a scan map of 60x10 arcmin, our goal is to map this narrow region without being interested where is the centre of the map but we want our target centre to be always included and to be on the edge of the map. I.e. our target coordinates will be the pivot point of the scan map.

Procedure 6.5. Setting scan map observations with centre offset

1.   Create the AOR following the steps from the previous section.

2.   Do not set any centre offsets now, keep them zero for the moment.

3.   Overlay the AOR on an image, in our case it will be ISSA image at 100 μm and choose a date in the beginning of the visibility window: for this example we choose 26 Sep 2008.

4.   From the "Overlays" pulldown menu overlay the "Herschel focal plane". By default it will be at position angle zero and at the target coordinates. If it is not, this may be because you configured the focal plane during an earlier example, set it now to Centred. We need to change this angle in the *Herschel control box* on the right to the actual position angle at the time of the observation. This can be taken from the *AOR Pointing table* (which opens when pressing the third button from the AOR control panel on the right, labelled with the name of our AOR: "SPhoto-LH-LMA") and we can see at the bottom of the AOR pointing table that it is 158 deg. Close the AOR pointing table and enter 158 in the box under Herschel panel on the right and press return. The Herschel focal plane is centred on the target position and the resulting overlay with the corresponding position angle is shown in Figure 6.62 (along with distance tool measurements that are added in the next point).
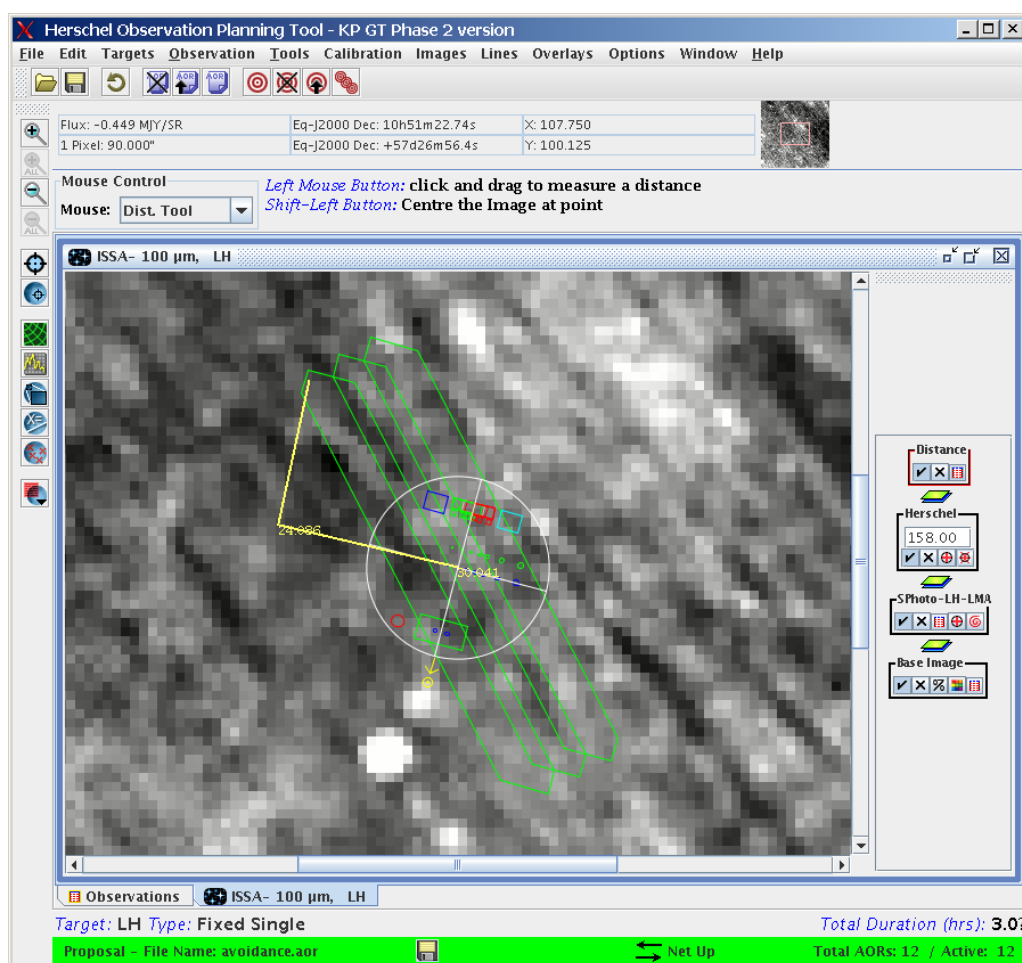

Figure 6.62. Large map 60x10 arcmin AOR overlay on the 100 μm IRAS image and the Herschel focal plane for 2008 Sep 26. The Distance tool measurements (in yellow) are shown.

5.   Let's say we want our pivot point to be on the first scan leg looking from North to South (the first scan leg is found by watching the animation of the AOR via the pointing table (3rd icon)). Then we need to figure out, in the Z, Y coordinates, what is the distance to the centre of the first (or the last) scan leg. Note that the +Z coordinate axis is always towards the Sun, while +Y axis is on the left if +Z points up (see Figure 2.1). In this case, using the "Distance Tool" (which is an option in the "Overlays" pulldown menu, see Figure 6.38 or one of the buttons on the left of the image) we derive Yoffset = 30 and Zoffset = 24 arcmin as shown in Figure 6.62 by the dark yellow lines. We enter these centre offsets in the AOR and replot the overlay to

check if that's what we want. We can repeat this until we are happy with the position of our pivot point (the centre of the overlaid Herschel focal plane). The result is shown in Figure 6.63.
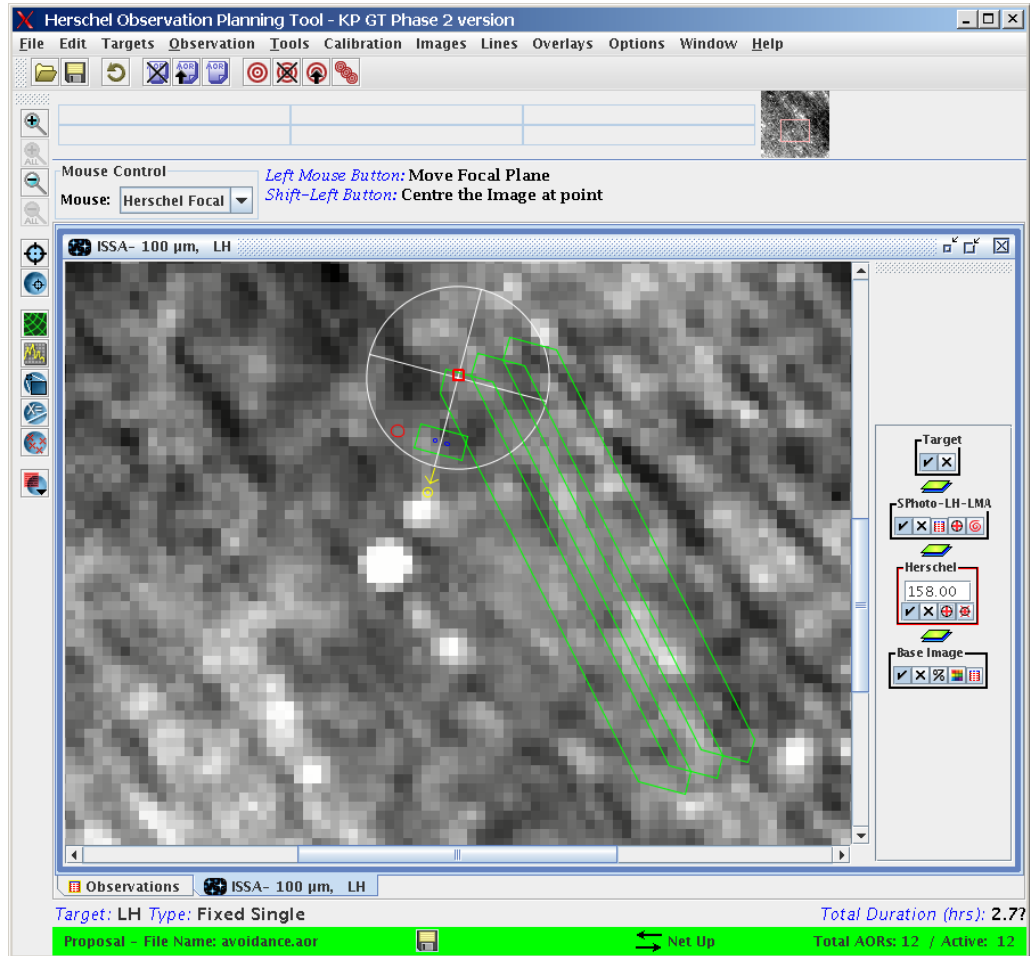

Figure 6.63. Large map 60x10 arcmin with offset centre AOR overlay on the 100 μm IRAS image and the Herschel focal plane for 2008 Sep 26. With centre offsets set to Yoffset=30, Zoffset=24 arcmin. For clarity we have removed PACS and HIFI instruments from the Herschel focal plane overlay and the map pivot point is marked by the small red box at the centre of the Herschel focal plane.

6. We can overlay the AOR on another date, for example the last day of the visibility window and check that in the whole visibility window our map rolls around the pivot point and have an idea on what possible coverage our elongated map will cover. Even we can add the middle date in the visibility window 2008 Nov 8 and overlay it: the result is shown in Figure 6.64. Note that it is not necessary the pivot point to be included in the map, it can be outside.
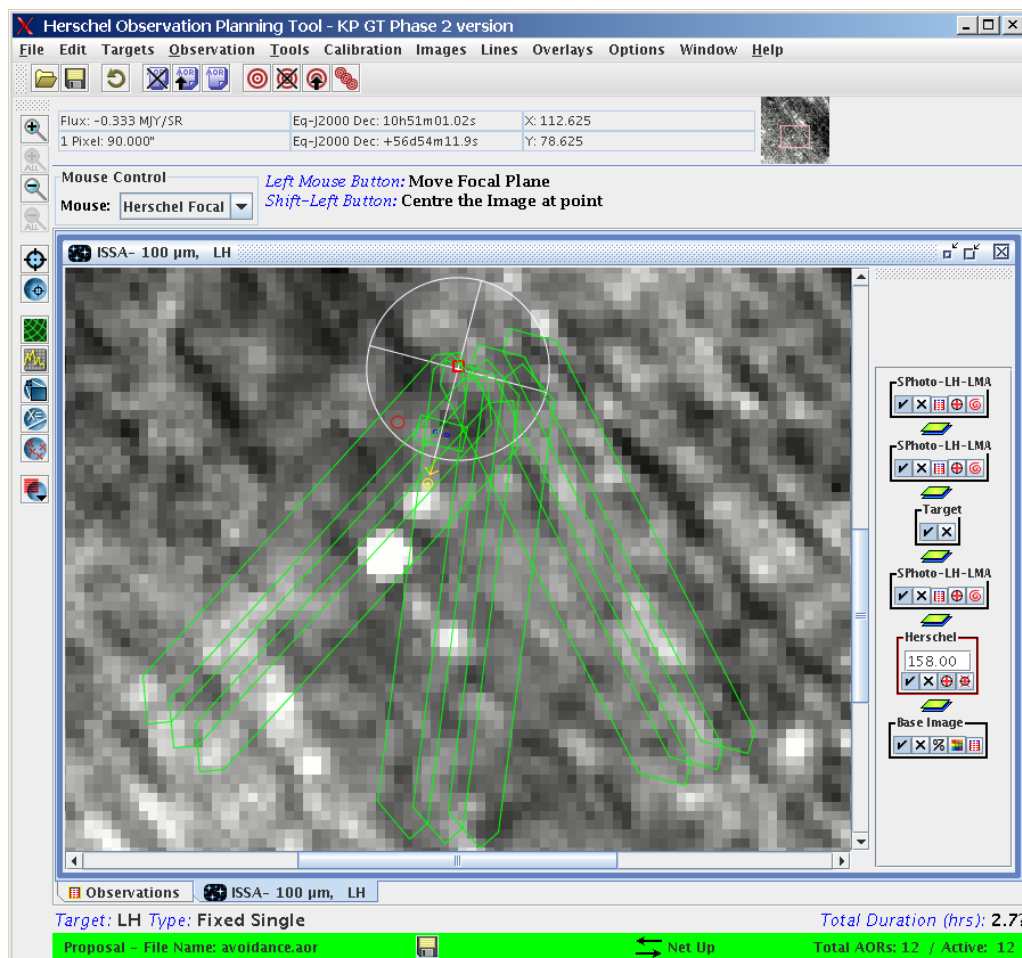
Figure 6.64. Large map 60x10 arcmin with offset centre AOR overlay on the 100 μm IRAS image and the Herschel focal plane. Map centre offsets set to Yoffset=30, Zoffset=24 and three possible observing dates: the beginning, the middle and the end of the visibility window (2008 Sep 26, 2008 Nov 9 and 2008 Dec 23). The pivot point of the map is marked by the small red box at the centre of the Herschel focal plane.

6.6.6. SPIRE Photometer large map with array constraints

Let us suppose that the region we want to be mapped is with constrained sky orientation, for example we want our 60x10 arcmin region from the previous example to have the large axis of the map aligned to the North direction ± 5 deg. Then in the initial window of the SPIRE Photometer AOT, in the Orientation box, we can set "Array with Map Constraint" pulldown menu which will make active the input boxes for two angles. We enter the two angles as shown in Figure 6.65.

Figure 6.65. SPIRE Photometer Large Map initial window with map angle constraints.

Next, it is important to check the if this map orientation constraint can be scheduled, i.e. that the change of the map orientation throughout a visibility window covers days when the map Scan A angle is between 355 and 5 degrees. The following steps are necessary because HSpot does not take into account constrained observation for the calculation of the target visibility.

The two map constraint angles correspond to two sets of Herschel focal plane position angles. Following Equation 4.1, we have to check when the focal plane position angle is between 323 and 313 degrees (or modulus 180, between 133 and 143 degrees). For this we can either use the visibility tool from the target window (See Step 2.b in the example in Section 6.6.1) or use the AOR overlay as we show in the following.

We overlay the AOR at the beginning and at the end of one of the visibility visibility windows (for example, on 24 Mar 2009 and on 23 June 2009). We follow the example in Section 6.6.2, Step 1 to do this. The overlay is shown in Figure 6.66. As in the above mentioned example, we take note of the two Herschel focal plane position angles for the two dates. We have 336 deg and 268 deg respectively. This means that the scan direction (Scan A) of the middle scan leg at these two dates will be ~18 deg and ~310 deg (adding 42.4 to 336 and 268) which we can verify qualitatively by looking at the overlay: Figure 6.66. It is advisable to put a coordinate grid (shown as yellow lines) of the equatorial RA, Dec system to make sure where the North direction of the underlying image is. Indeed, the two scan maps large axes (Scan A direction) seem to be correct (i.e. at ~18 and ~310 deg).

We might check with another day in the middle of the visibility window (for example on 8 May 2009) to make sure that indeed the map rotates from large axis direction angle 18 deg East of North to 310 deg passing over the North direction. Consequently there will be dates in the visibility window when the map orientation will be inside our constrained range. With some play with the visibility tool we can check when the position angle of the Herschel focal plane is 318 deg ±5 (i.e.

between 313 and 323): this results in dates between 10 and 23 Apr 2009. We can overlay an AORs for a date inside these two dates and verify that our map orientation corresponds to what we wanted.

Warning

The visibility window shrinks from 92 days to only 13 days with this example of map orientation constraint. For each constrained observation request, the observer is penalised by 10 minutes observing time because the mission planning becomes more complicated and less efficient and therefore effectively take up more Herschel time (hence the larger observation overhead).
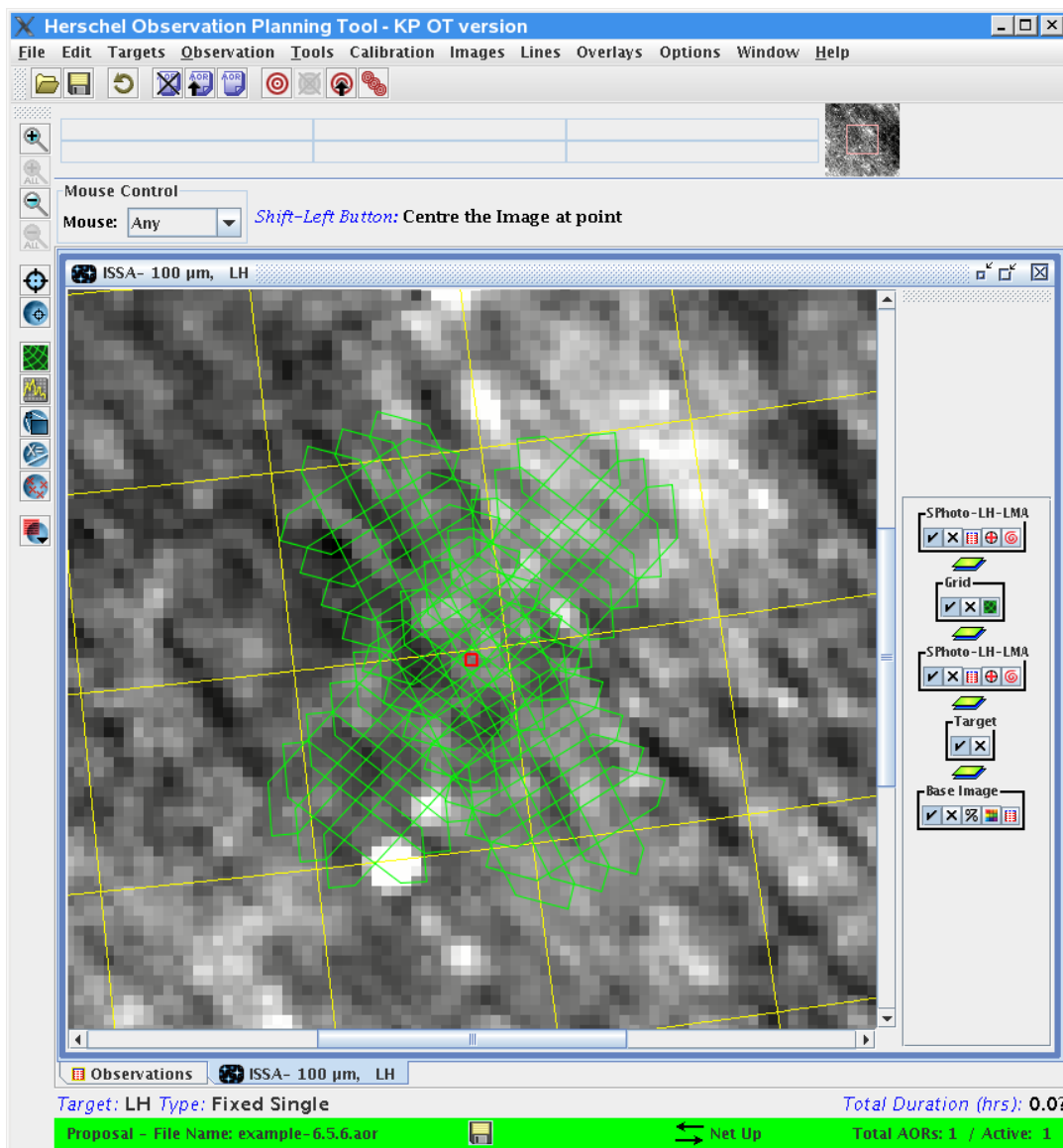

Figure 6.66. Large map 60x10 arcmin AOR overlay on the 100 μm IRAS image. The scan map is shown for two extreme dates in a visibility window.

The above example must be extended to cover map angles modulus 180 degrees. Which means that we need to check Herschel focal plane position angles between 133 and 143 deg too (covers the case of map angle at 180 deg ± 5 deg).

Let now see how can we proceed if we want our map angle to be at 90 ± 5 deg. In this case we see from the calculations above that we cannot schedule such observation if we only want Scan A angle to be used, because there are no dates when the position angle of the Herschel focal plane is between

43 and 53 degrees (or 223 and 232 degrees for modulus 180 deg). We can check if we can use Scan B angle instead. Following Equation 4.1 (Scan B case), we derive that we have to find when the focal plane position angle is between 127 and 137 degrees (or modulus 180, between 307 and 317 degrees). After following the same procedure as for Scan A angle, we find that the corresponding dates in the same visibility window (March - June 2009) are from Apr, 18th to May, 2nd 2009. If our observation is with cross-linked scans then we have to swap the length and the height of the map, so doing 10x60 arcmin map. Because of the cross-linked character of the observation, the result shown in Figure 6.67 is what we asked for.
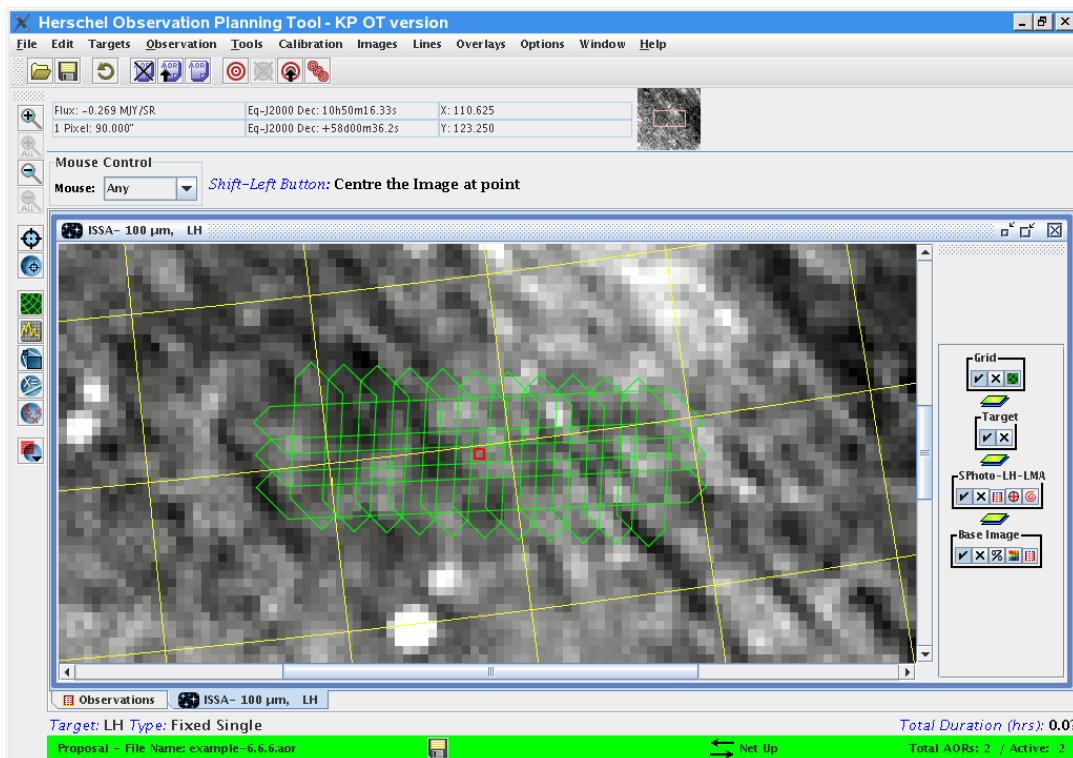

Figure 6.67. Large map 10x60 arcmin AOR overlay on the 100 μm IRAS image. The scan map is shown for 2009 May 1st. The map large axis lies at 90 ± 5 deg east of north.

Using the above consideration it is clear that regardless of which scan angle we use Scan A or Scan B, if we want our 60x10 arcmin map large axis direction to lie on 30 deg East of North direction, then this observation cannot be scheduled: there are no dates when the Herschel focal plane position angle is near 348 deg (Scan A) or 168 deg (Scan B). In this case the observer could increase the map area so that the region of interest is included regardless of the date of observation. A square map of size 85x85 arcmin is the minimum that will cover the 60x10 arcmin region.

6.7. Example: SPIRE Spectrometer

Important

In the following examples we assume the reader is familiar with (i) the observing modes for the SPIRE Spectrometer as explained in Chapter 4 and (ii) with the basic usage of HSpot as explained in the HSpot Users' Guide.

Note

The AOR files for the examples in this section, as well as a fits image for one of the targets (NGC7252) are available in a zip file and can be downloaded from here.

When the observer chooses the SPIRE Spectrometer observation from the initial HSpot screen then the window shown in Figure 6.68 appears with different options and a possibility of two pointing modes, three possibilities for spatial sampling and four spectral resolution modes. The number of the possible combinations is 24, and consequently observations with the SPIRE Spectrometer require careful analysis and any additional information is useful in order to choose the most efficient options.
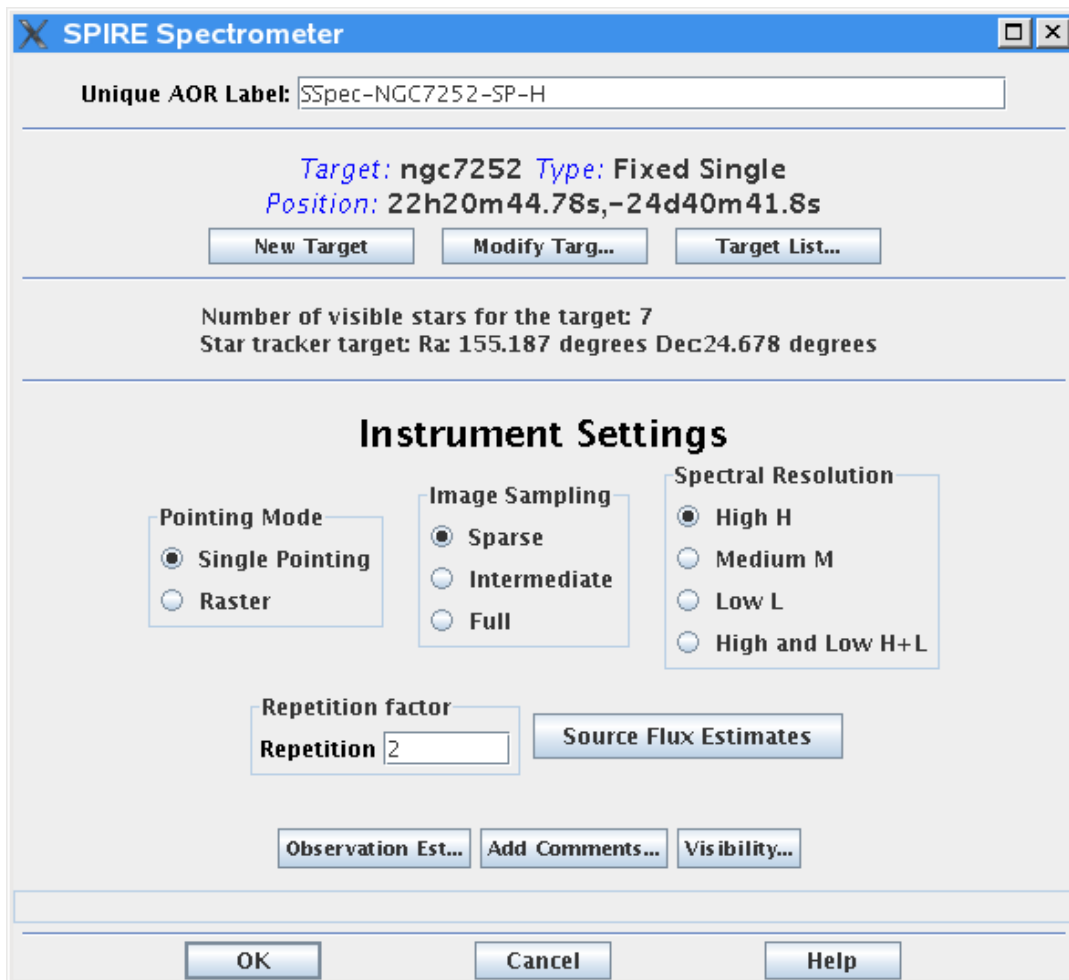

Figure 6.68. Initial screenshot of the SPIRE Spectrometer with H spectral resolution.

The choice of the pointing mode and spatial sampling is in most cases straightforward, i.e. single pointing for a point source, or raster for areas larger than 2 arcmin diameter area; sparse, intermediate or full sampling depending on the object and its spatial extent. The choice of the spectral resolution mode, however, is not that obvious due to the peculiarities of Fourier-Transform spectroscopy. In this case, any additional information such as estimates of the continuum level or line fluxes is beneficial. In the examples below we try to illustrate some points of consideration when planning SPIRE Spectrometer observations.

Note

Note that the considerations presented in the following example hold for any of the image sampling settings (sparse, intermediate or full) as well as for raster observations.

6.7.1. SPIRE Spectrometer Single Pointing Mode, Sparse Sampling

For all examples below we shall use NGC 7252 galaxy as our object. Step 2.b from Section 6.6.1 example should be followed to resolve the name or to enter the coordinates (as found for example from SPIRE Photometer observations), check the visibility and the background. The galaxy is definitely not a point source but this is irrelevant for the examples. Our science project requires line measurements with at least signal-to-noise of 3.

The example includes a number of trial and check steps because the sensitivities for the continuum in the current HSpot version do not reflect the fact that high and medium resolution spectra can a posteriori be processed as low resolution ones.

1. On the SPIRE Spectrometer observation initial window (Figure 6.68) we choose Pointing Mode: "Single Pointing", Image Sampling: "Sparse" and Spectral Resolution: "High". Note that the repetition value is set to the default minimum of two: it is not possible to perform this observing mode with less than two repetitions.

2. Optionally, if there is an estimation of the source line flux and continuum at certain wavelengths, you may enter the values by pressing the "Source Flux Estimates" which brings up the window shown in Figure 6.69. We have entered some purely fictitious values which have no connection with the real values for NGC 7252. Note that you will not be allowed to enter wavelengths outside the SPIRE range of 194-672 μm.

Figure 6.69. SPIRE Spectrometer: Source Flux Estimate table.

3. By pressing the "Observation Est..." button, an estimation of the observation time can be obtained as shown in Figure 6.70.

    Now we need to investigate the resulting sensitivity values: we see that the SNR for the two lines of interest at 211 and 266 μm is not sufficient, so it is necessary to increase the repetition factor in order to get SNR greater than 3. We ignore the line at 400 μm as it is very weak.
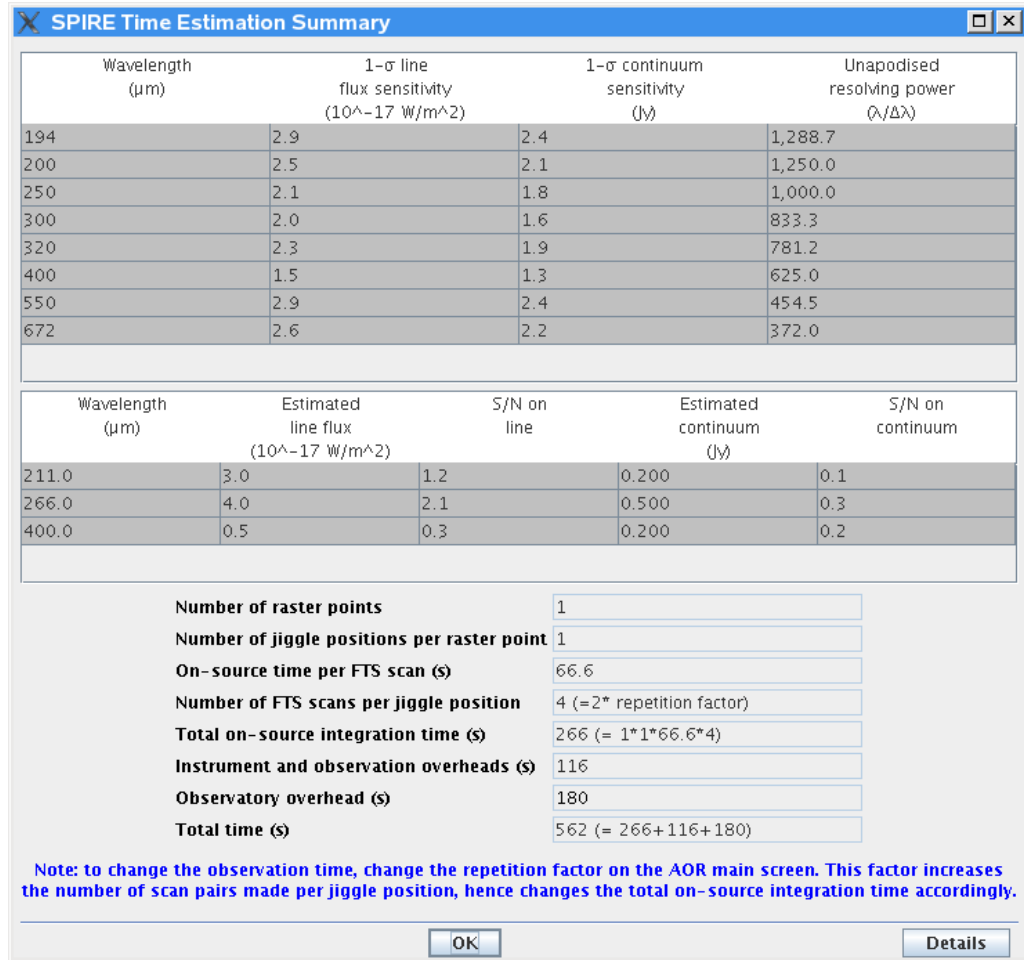
Figure 6.70. Time estimation for the SPIRE Spectrometer, single pointing, sparse sampling and high spectral resolution. Default repetitions of 2.

After a couple of attempts and checks with different repetition factors we see that with 12 high resolution repetitions we achieve our goal of SNR of 3 for the two lines. The time estimate for this case is shown in Figure 6.71.
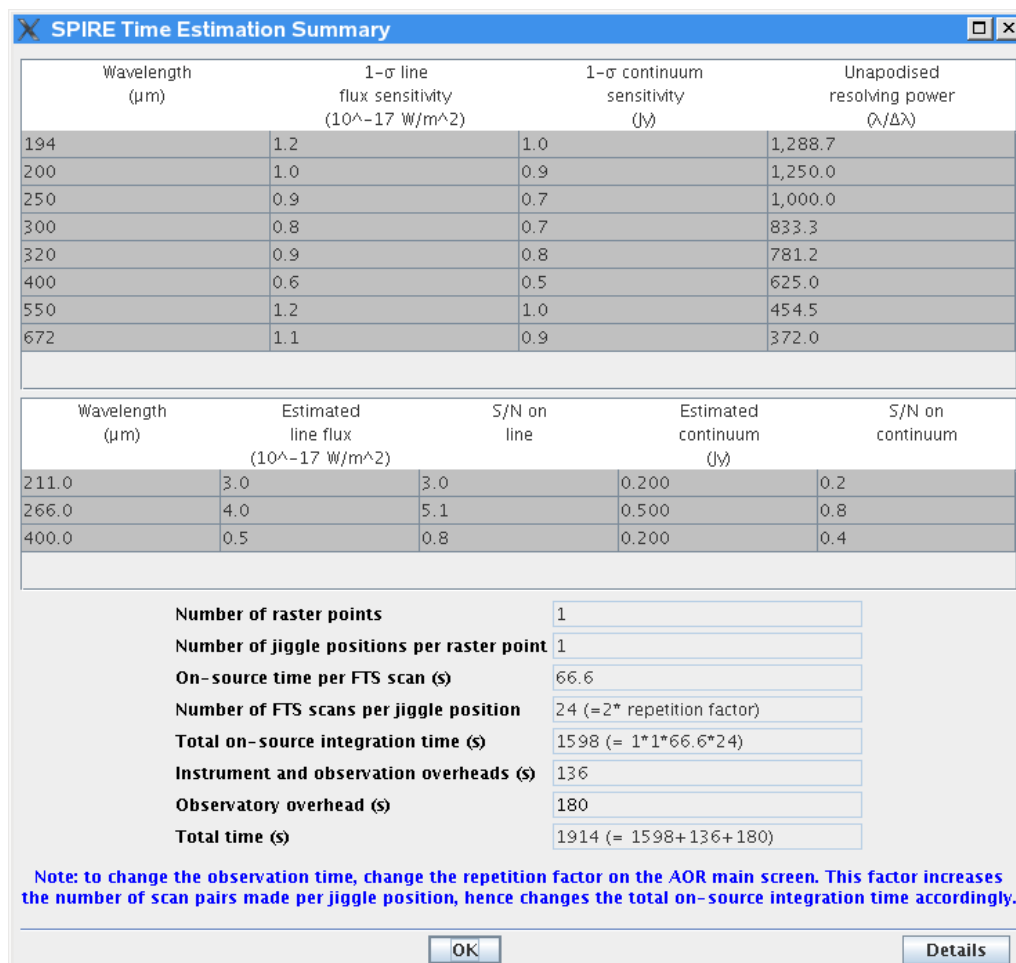
Figure 6.71. Time estimation for the SPIRE Spectrometer, single pointing, sparse sampling and high spectral resolution. The repetition factor is set to 12.

The estimate of the continuum sensitivity shown in Figure 6.71 is for the final high resolution spectrum. However, as discussed in Section 4.2.1, it is also possible to extract a low resolution spectrum from the same observation. Currently, the only way to estimate the sensitivity of the continuum in this extracted low resolution spectrum is to switch to "low resolution" mode and enter the same number of repetitions (in this case we used 12). We close the time estimation window for the high resolution mode by clicking the "OK" button and then we change the spectral resolution to "Low L" and execute the observation estimation again. The resulting time estimation and sensitivities are shown in Figure 6.72.
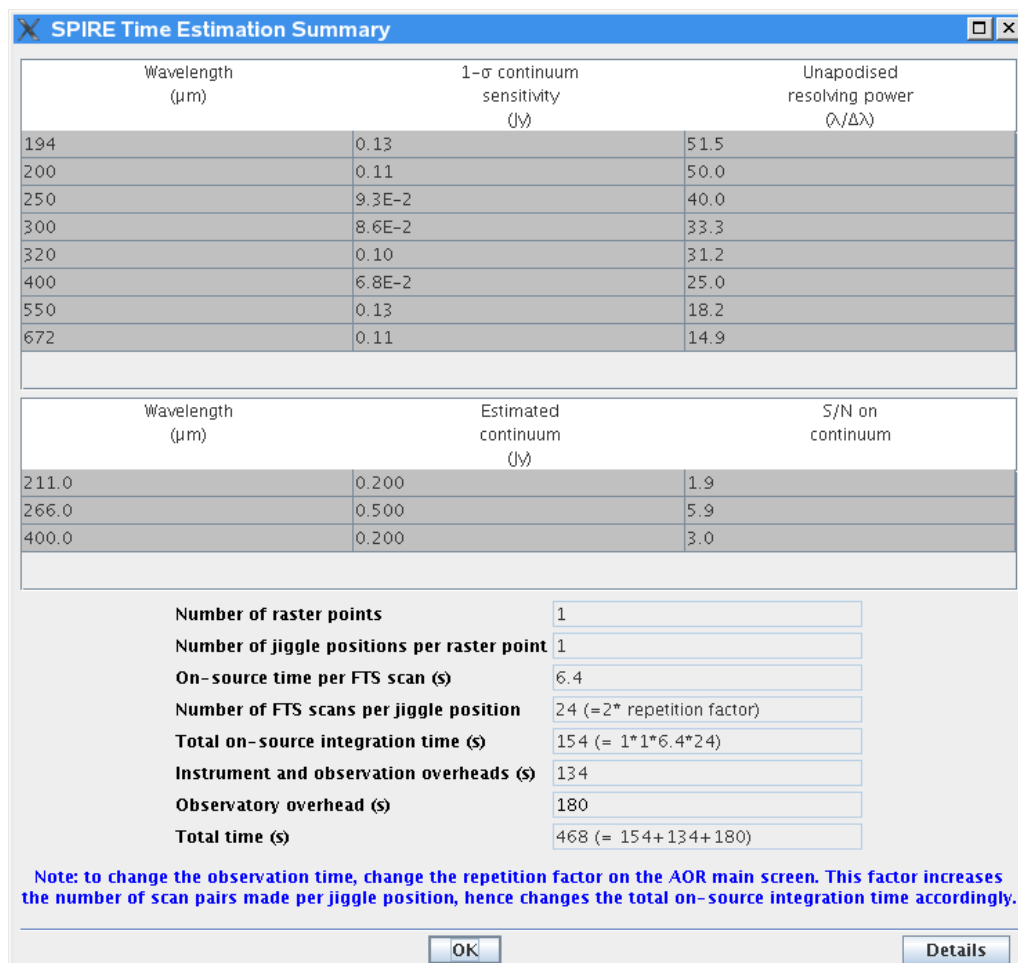
Figure 6.72. Time estimation for the SPIRE Spectrometer, single pointing, sparse sampling and *low* spectral resolution. The repetition factor is set to 12.

If this low resolution continuum level is satisfactory then we can switch back to the high resolution observing mode and proceed from Step 4 in the recipe below.

If we need better signal-to-noise for the low resolution continuum (e.g. at 211 μm it has a signal-to-noise ratio of 1.9) then we can increase the low resolution repetition factor until we reach our goal signal-to-noise ratio of 3. After a couple of trials we see that we need 30 low resolution repetitions to achieve low resolution continuum with signal-to-noise ratio of 3 at 211 μm for the estimated continuum level of 0.2 Jy.

This result shows that the "High and Low" observing mode would be more suitable for our observation because the required repetitions for the high and low resolution scans are different. Following from the discussion of this mode in Section 4.2.1, we have nH=12 (high resolution repetitions), and we require $nL+nH$=30 (total number of low resolution repetitions). Thus nL=18 (=30-12) and we can set up the H+L observation as shown in Figure 6.73. The corresponding time estimates are shown in Figure 6.74.

Figure 6.73. Time estimation for the SPIRE Spectrometer, single pointing, sparse sampling and high and low spectral resolution. The repetition factors are 12 and 18 for high and low resolution scans respectively.
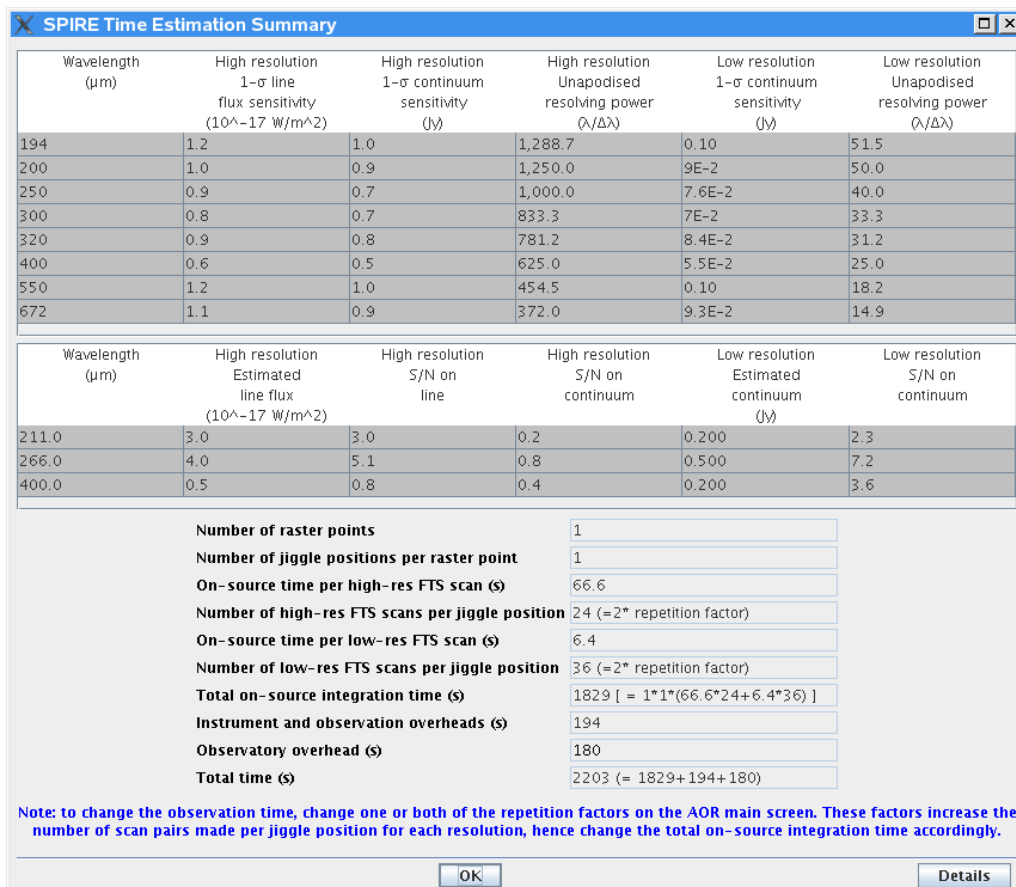
Figure 6.74. Time estimation for the SPIRE Spectrometer, single pointing, sparse sampling and high and low spectral resolution. The repetition factors are 12 and 18 for high and low resolution scans respectively.

Warning

The continuum sensitivities shown in Figure 6.74 do not reflect the fact that the high resolution scans can be reduced as low resolution ones, and therefore be used to add up to the final sensitivity estimate. This will be changed in a future version of HSpot.

If we are satisfied with this set up then we may proceed further and look at the detailed timeline and visualise the AOR with the following steps:

4. Details of the exact breakdown and structure of the observation can be obtained by pressing the "Details" button and we show it for verbosity level-1 in Figure 6.75).
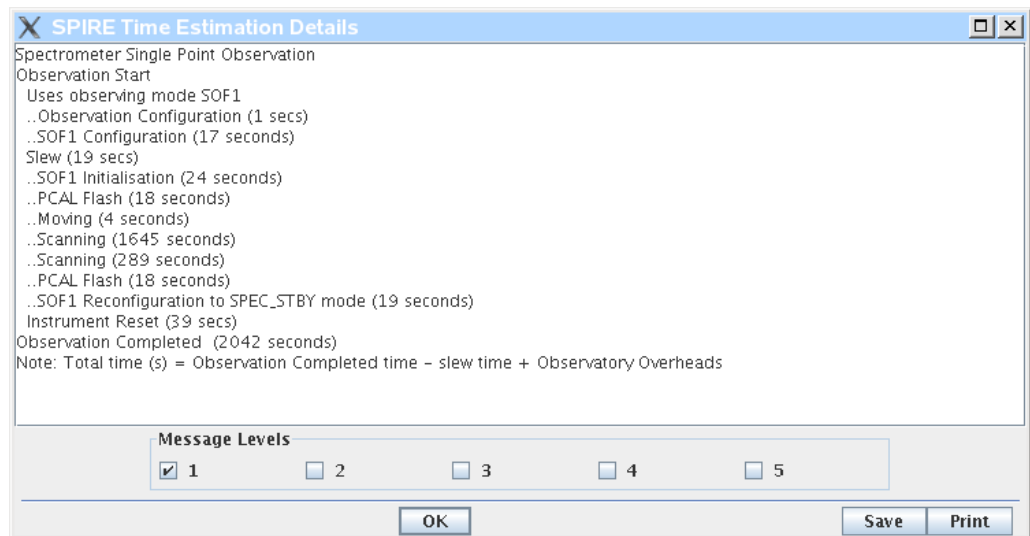
Figure 6.75. Detailed time breakdown for the SPIRE Spectrometer, single pointing, sparse sampling and high and low spectral resolution with repetition factors 12 and 18 (level-1 verbosity).

5.   The visualisation of the AOR follows Step 6 of the example in Section 6.6.1 example. The result is shown in Figure 6.76.
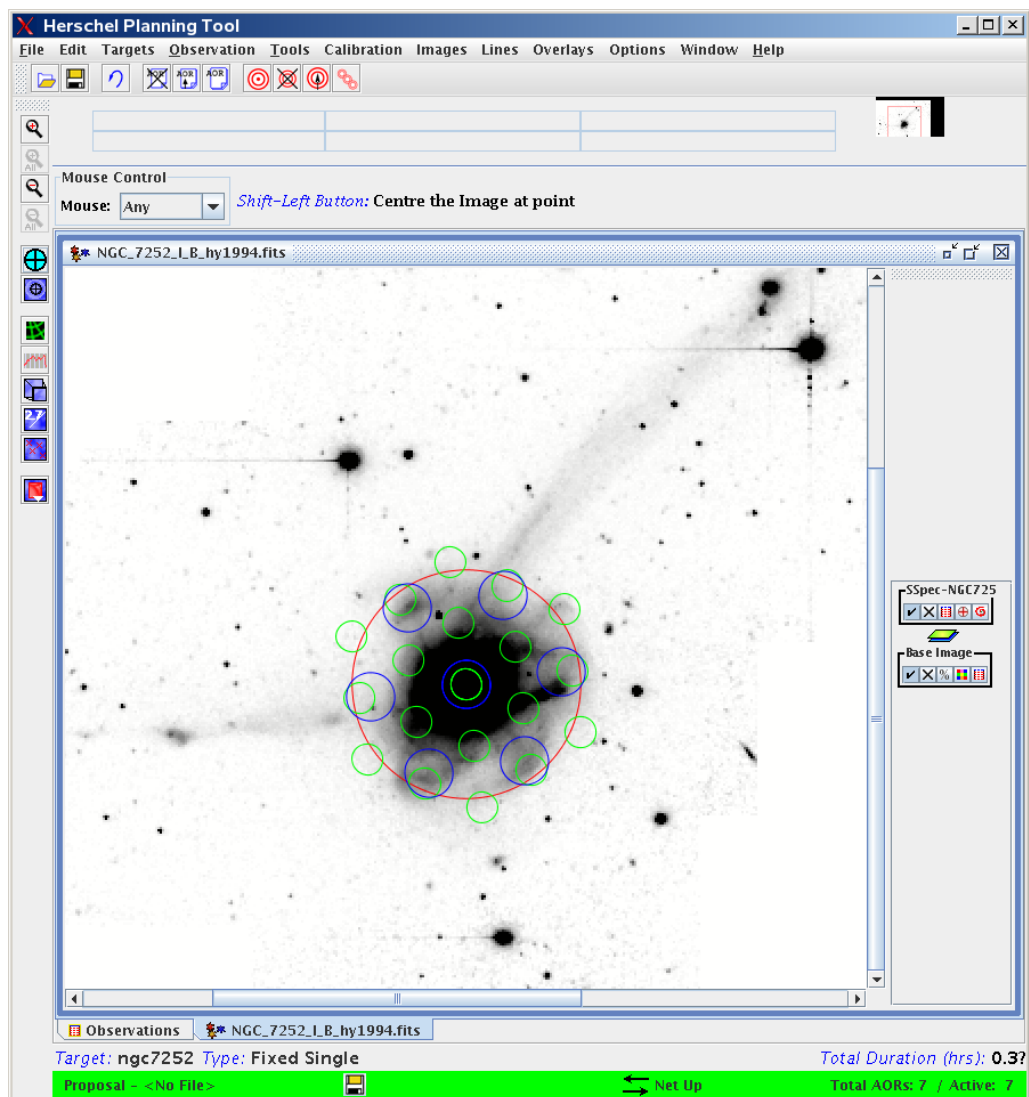
Figure 6.76. Single pointing SPIRE Spectrometer observation. The image is a user supplied CTIO B-band optical image. The blue and green circles are the SLW and SSW detectors, the unvignetted field is indicated by a red circle with 1 arcmin radius.

6.7.2. SPIRE Spectrometer Raster Mode

We only give an example of the Raster mode for intermediate spatial sampling and medium spectral resolution. Please follow Step 2.b from the example in Section 6.6.1 to set up the target, resolve the name or to enter the coordinates, check the visibility and the background.

6.7.2.1. SPIRE Spectrometer Raster Mode with intermediate spatial sampling and medium spectral resolution.

1. From the initial SPIRE Spectrometer observation window choose Pointing Mode: "Raster", Image Sampling: "Intermediate" and Spectral Resolution: "Medium M". With this choice we have to input the raster map length and height and we use 4x6 arcmin for this example as shown in

Figure 6.77.

Figure 6.77. Initial screen for the SPIRE Spectrometer, raster map, intermediate spatial sampling and medium spectral resolution.

2. Optionally, if there is an estimation of the source line flux and continuum the user may enter the values by pressing the "Source Flux Estimates" which brings up the window shown in Figure 6.69.

3. By pressing the "Observation Est..." button an estimation of the observation time can be obtained as shown in Figure 6.78.
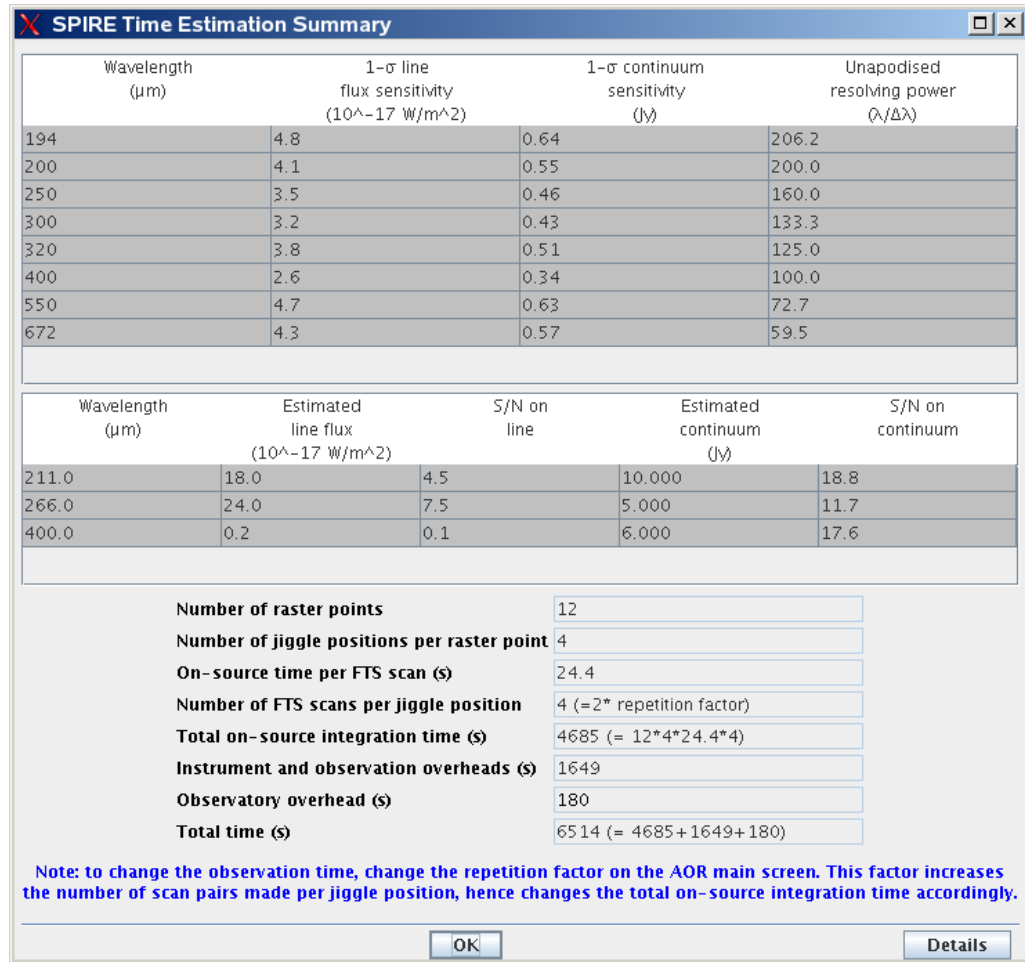
Figure 6.78. Time estimation for the SPIRE Spectrometer, raster map, intermediate spatial sampling and medium spectral resolution.

4. The visualisation of the created AOR follows Step 6 from the example in Section 6.6.1. The result is shown in Figure 6.79. Note that only the unvignetted field of 1 arcmin radius is indicated (the red circle). In each of the red circles the sampling follows Figure 4.12. Note as well that map centre will not be placed directly at the centre of one of the raster positions. That is why in raster mode it is very important to visualise the AOR and when there are doubts or problems then follow the next example.
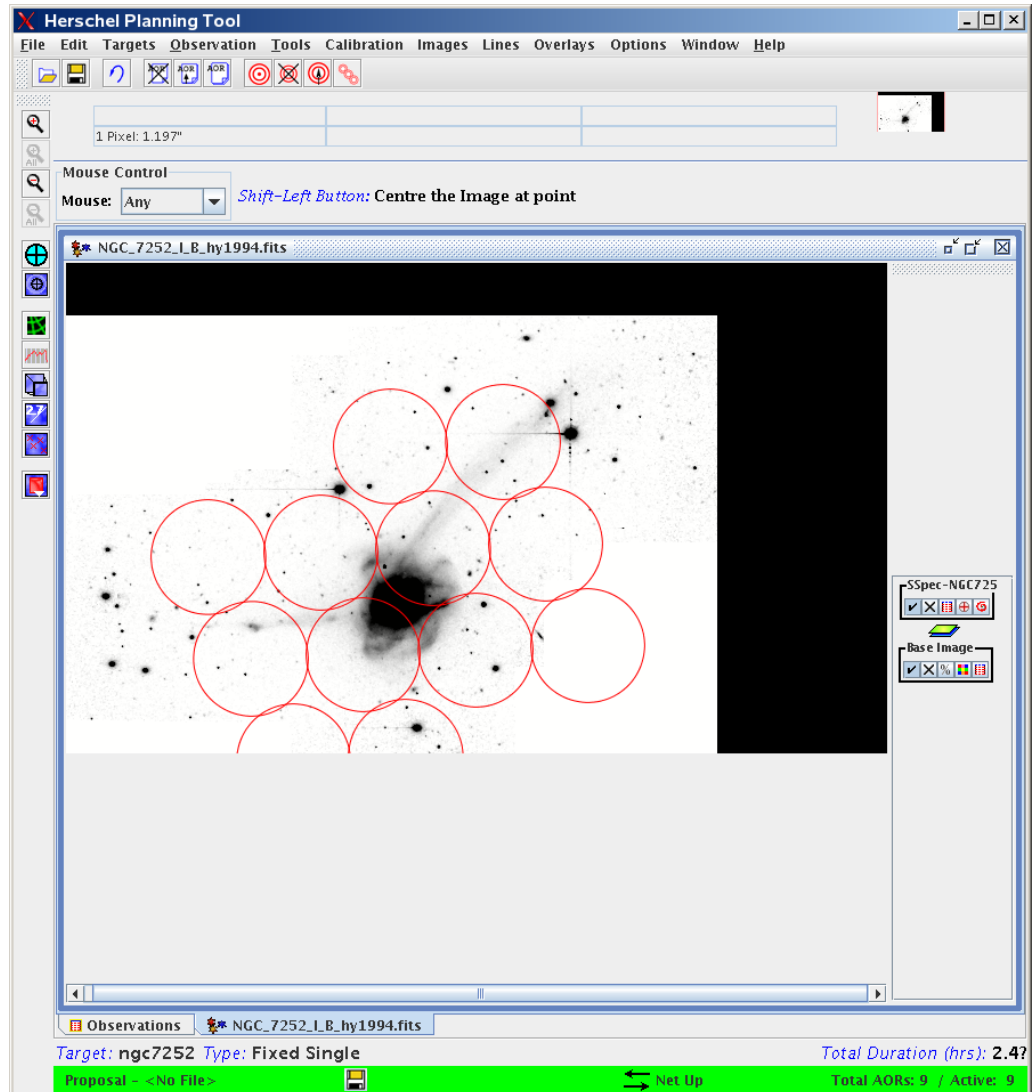
Figure 6.79. SPIRE Spectrometer raster observation. The image is a user supplied CTIO B-band optical image, and approximate Spectrometer footprints (red circles with 2 arcmin diameter) at each raster positions are shown. Note the user supplied target centre (the small red box) is not at the centre of a raster position!

6.7.3. SPIRE Spectrometer Raster Mode: tailoring the map area to the source shape

The raster mapping direction for the spectrometer is fixed with respect to the spacecraft axes in order to optimise coverage from the hexagonally packed arrays. This means that the visibility constraints may mean that the standard raster is not well aligned with the proposed source emission. Particularly for sources near the ecliptic that do not rotate very much through each visibility window.

In the following recipe, the galaxy NGC253 is used as an example source, as it has extended emission aligned in a direction that cannot be mapped in a simple way because of the spacecraft position angle constraints. The objective of this example observation is to map along the plane of the galaxy covering a strip of approximately 20x4 arcmin.

For NGC253, there is very little choice of position angle - during each visibility window the position angle varies by about 34 degrees between 227 degrees and 261 degrees (or the corresponding angles 180 degrees away). This puts the raster direction between 48 and 82 degrees to the disk of the galaxy.

As an example of the strategy to employ to minimise the number of raster positions, we will assume the middle date in each visibility window, putting the raster direction at 65 degrees to the plane. In this case, a full raster of 17x12 arcmin (10x8 raster points) is required to cover the disk. The following recipe shows the strategy to tailor the map to the source in order to minimise observing time.

Procedure 6.8. SPIRE Spectrometer Raster Mode tailored to the source structure.

1. Firstly, we create a standard AOR with the full oversized raster that contains everything we want to cover. We must either make sure this is big enough for the worst case visibility window, or apply a sky constraint to the map angle. For NGC253, we will constrain the observation to be made near the centre of the visibility window with a position angle of 244 degrees. In that case, 17x12 arcmin (10x8 raster points) are required to cover the disk.
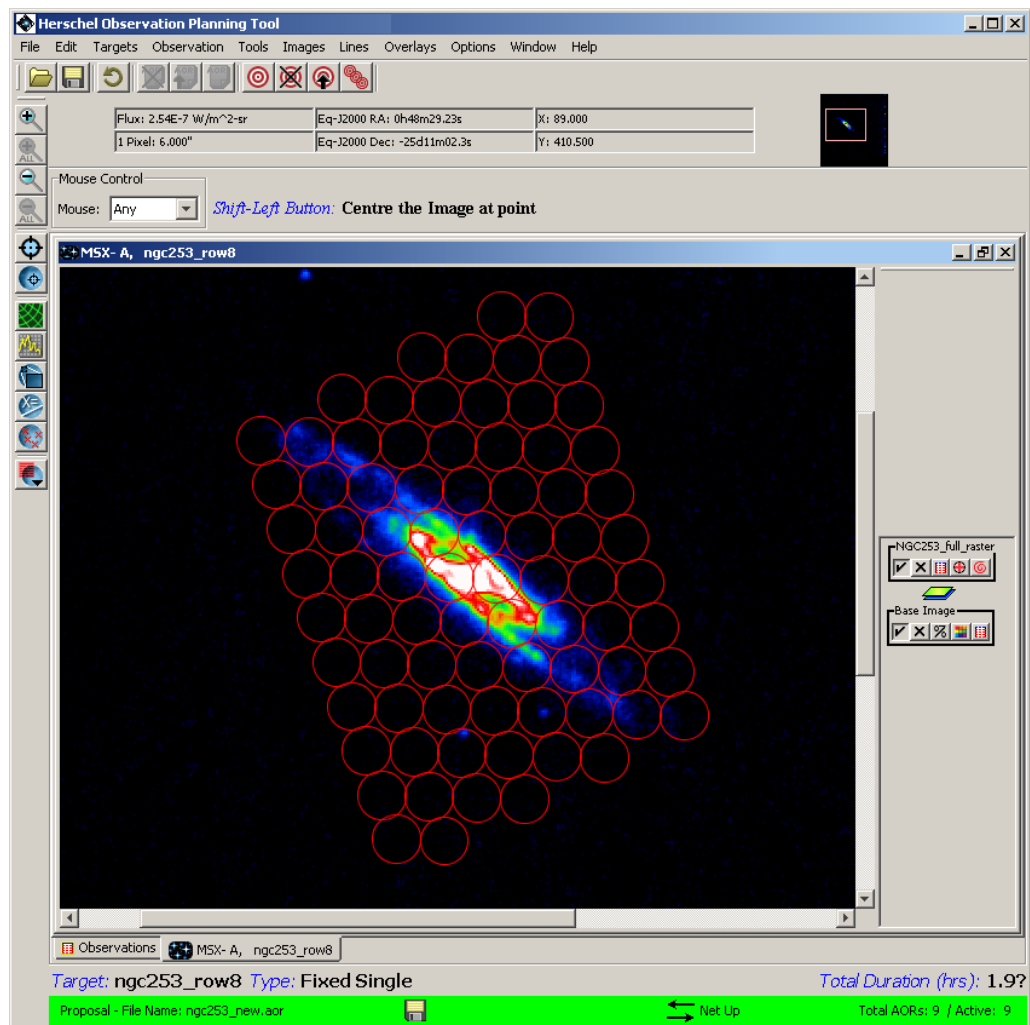

Figure 6.80. SPIRE Spectrometer raster map, covering NGC253 with a 10x8 point raster. This AOR is overlaid on an MSX 8.28 μm image of the galaxy.

2. Find an image and visualise this AOR (This is shown in Figure 6.80 using an MSX 8.28 μm image as the background).Redisplay this AOR for different dates within each visibility window

to find the best angle constraint to apply.

3. In the selector buttons on the right of the image for the AOR, select the middle button for the 'Pointing Table'. This will display the coordinates of each raster point. In this Pointing Table, the first column can be used to specify which different raster fields are displayed on the image. We use this to turn off the raster fields that are not needed until the desired coverage is achieved. In this way, it is possible to reduce the total number of raster points for NGC253 from 80 to 30. The selected fields for NGC253 are shown in Figure 6.81.
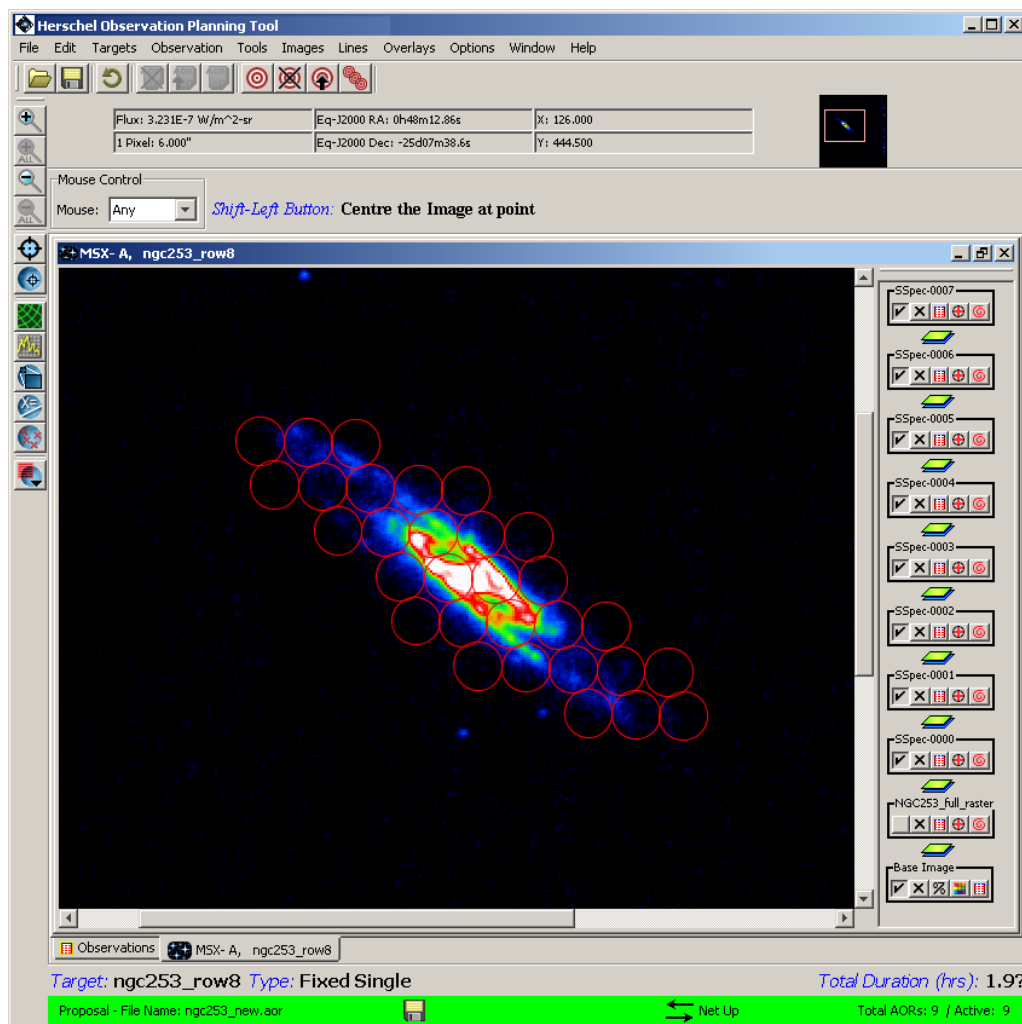
Figure 6.81. Selected fields to cover the disk of NGC253.

4. We then divide the selected fields into individual AORs (e.g. each row as a separate AOR, or groups of rows together). Rows are easiest to construct: in this example for NGC253, 8 individual rows can be selected (to form a single row, set 'height' to 0.9 arcmin). We then create a 'Target List' containing 8 new sources using the centre of each row for the coordinates. For odd numbers of raster points this is the coordinates of the center raster field directly read from the Pointing Table. For even numbers of raster points, this is the average of the central 2 positions. Note: the coordinates are given in decimal degrees in the Pointing Table and to enter RA correctly in the target dialogue, we must add 'd' after the number: e.g. 11.3456d. Also note here that each of these individual rows will rotate with the visibility window and so the same angle constrain must be applied to each one. Applying a constraint may be the only way to ensure that all of the separate AORs are observed at the same angle.

5. Concatenate these 8 AORs by clicking on the Tools menu at the top of the screen: Tools -> Group/Follow-on constraints -> Add Concatenation. Then click and drag the AORs into the

concatenation in the correct order, as shown in Figure 6.82. Note that the 180 second slew tax will still be applied to each one because the source coordinates are different but the 10 minute angle constrain tax will only be applied once for the entire concatenated chain.

Figure 6.82. Concatenated AORs for the raster example.

6. Check the visualisation at different dates within the constraints. If done correctly, the 8 new AORs for NGC253 should cover the the same field locations as those selected from the over-sized 10x8 position map, and each individual row should line up to give the final coverage.
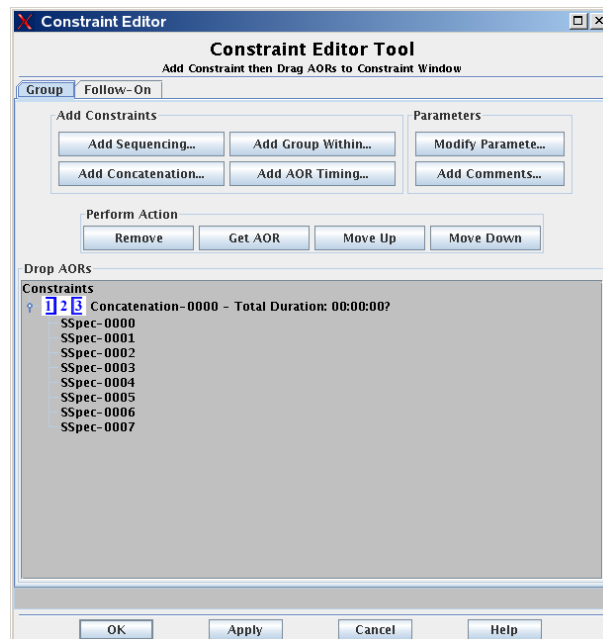
The technique described above is the best one to adopt for tailor made maps because it maintains the optimum field spacing in the raster (as it takes the positions from the official AOR). The field spacing along rows used in the official AOR is 116 arcsec, and between rows is 110.6 arcsec. These values are based on the fact that the actual coverage in each field is not really circular (for intermediate and full sampling at least) and so a simple hexagonal pattern (spacing along a row of 120 arcsec and between rows of 103.9 arcsec) would not give the optimum coverage and spacing across the map.

The other option would be to create a raster from scratch using a single pointing in each AOR. This may be advantageous for the high spectral resolution mode with full spatial sampling, as each raster field takes a long time to observe relative to the overheads for one AOR. However, each field would then be free to rotate on the sky depending on the observing date and so a visibility angle constraint would be required to maintain the optimum coverage pattern. Gaps in coverage between fields can not be ruled out if rotation of individual fields is allowed, or if a different raster step is used, without checking the exact pixel layout within each field for the sky angle used.

In the above example, for a sparse high resolution raster, the original oversized map with 80 raster points took 7 hours 20 mins. The concatenated tailored map with 30 raster points takes 3 hours 24 mins including an angle constraint.

Chapter 7. Data product expectation and SPIRE pipeline

7.1. SPIRE data deliveries

Warning
This Chapter should be taken as preliminary because the pipeline and the standard product generation and deliveries are still in development phase.

7.1.1. Observation context and Product Access Layer

Each observation with SPIRE results in scientific, calibration, housekeeping and auxiliary data (in form of telemetry packets or dataframes). This data is embedded in a so called *observation context*, which is a holder of references to everything a given observation needs in order to run the Standard Product Generation (*SPG*) pipeline or already processed higher level scientific products. The content of the observation context is shown in Table 7.1. The SPIRE pipeline, as well as the pipelines of the other two instruments, are all part of the SPG and they process the raw data into products at level-0, 1, 2 and store/update them in the observation context and at the same time filling the quality information with the quality assessment of each processing step.

Table 7.1. Observation context entries.

Entry	Description
auxiliary	The auxiliary products
calibration	The calibration products
telemetry	The raw telemetry packets
dataframes	The telemetry packets combined into dataframes
level0	Arranged telemetry packets in into products
level1	Level-1 products (see below)
level2	Level-2 products (see below)
quality	Quality assessment for the SPG run

All SPIRE observations are processed by the Herschel Science Centre and the content of the observation context is updated. The only mandatory information the observer has to know in order to access the data is the observation identification - the `obsid`.

7.1.2. Access to the higher level products

The highest levels of processing in the SPIRE pipeline are level-1 or level-2 products, depending on the observing mode (see Chapter 4). The instrument effects are removed as much as possible from these products. The summary of the contents is shown in Table 7.2.

Table 7.2. SPIRE scientific products in the observation context.

Level	Instrument	Observing mode	Description	Units
level-1	Photometer	Point source	Estimated flux	mJy
	Spectrometer	Point source	Spectrum product	mJy

Level	Instrument	Observing mode	Description	Units
level-2	Photometer	Small map	Map product with sky coordinates	mJy/beam
	Photometer	Large map	Map product with sky coordinates	mJy/beam
	Photometer	Small or large map	Point source catalogue	mJy

7.2. SPIRE pipeline

Note

The SPIRE pipeline is still in active development stage and consequently the information presented in this section is subject to changes.

The SPIRE pipeline is part of the Standard Product Generation and consists of processing tasks that are applied to the data in order to generate scientifically calibrated standard products which are created and updated inside an observation context. The pipeline can be run in an automated way or, whenever needed, the user can run it interactively step by step and control, verify or assess the products generated at each step.

In order to proceed with the description of how to run the SPIRE pipeline we need to introduce some concepts:

Telemetry Packets (TM)
The data from any observation with SPIRE comes in telemetry packets. These are stored in a database and can be retrieved from the Herschel Archive Browser if deemed necessary. In principle the observer will receive the data in high level products and only in exceptional cases a recourse to the telemetry packets will be necessary.

Products
All telemetry packets belonging to a given observation are arranged and then combined into data products. There are different types of products: science data, instrument housekeeping, telescope attitude products. And there are different levels of science data products: for SPIRE, depending on the observing mode, we have level-0, level-1 and level-2 products (see Table 7.2).

There is a similarity between Products and FITS files: the products contain meta information (like FITS keywords), history and one or more table or image datasets. The products are more comprehensive objects but can be exported as FITS files, which can be used outside HCSS if wanted/required.

Building Blocks
Each observation is split into building blocks (see Chapter 4). Most of the pipeline stages from level-0 to level-1 products operate on building blocks and the main reason for this is convenience: the amount of data of one observation can be huge and the data processing will be too resource hungry or even impossible to run if the whole observation has to be processed as one single block of data.

Pipeline task
Each pipeline module that manipulatse in some way the data, is coded as a task in Java.

7.2.1. Photometer and spectrometer common stages

The first two stages of the pipeline processing are common for both the photometer and the spectro-meter.

> **⚠ Caution**
>
> All this chapter must be taken as preliminary. All the stages are TBC.

Procedure 7.1. Common pipeline modules

1. Pre-requisites

   a. Loads the relevant calibration products depending on the observing mode: e.g. detector offsets table, BSM calibration tables, ZPD, etc. See Section 5.5. The observing mode is determined automatically from the meta information in the data products.

   b. Split the observation into building blocks. This is done automatically inside the pipeline master script. The pipeline will loop over the building blocks.

2. **level-0** stage

   Each of this stage sub-steps is performed on a single building block.

   a. reformat telemetry packets to timeline products

   b. mask bad channels

   c. convert ADUs to detector Volts (PDT/SDT) or Eng Values (the rest of level-0 timelines)

   d. add offsets to the PDT/SDT

   e. time conversion an re-ordering

   f. correct pixel times (PDT/SDT only)

Table 7.3. SPIRE level-0 products. TBC.

Product id	Description	TM packets
PDT	Raw photometer detector timeline	PHOTF,PHOTSW, PHOTMW, PHOTLWS
SDT	Raw spectrometer detector timeline	SPECSW, SPECLW
NHKT, CHKT	Raw housekeeping timeline (nominal+critical)	NHK, CHK
BSMT	Raw beam steering mirror timeline	BSMNOMINAL
SMECT	Raw spectrometer mechanism timeline	SMECSELECT, SMECSCAN
POFFT, SOFFT	Raw offsets timeline (photometer+spectrometer)	PHOTOFF, SPECOFF
SCUT	Raw subsystem control unit timeline	SCUNOMINAL

3. Stage 2

a. chop and jiggle (depending on AOT)

b. nod (depending on AOT)

c. first level deglitching

d. RC roll off correction

e. temperature and conductance

f. absorbed optical power

g. correction for sensitivity changes

h. straylight removal

i. crosstask removal

j. telescope temperature drift removal

k. flat-field correction

7.2.2. Photometer pipeline

The photometer pipeline tasks

Procedure 7.2. Photometer pipeline stage 3 and 4

1. Stage 3, scan mode only

    a. calculate the pointing

    b. correct for scan velocity

    c. associate to sky position

    d. photometer scan products (*Level-1* product)

    e. re-grid onto fixed sky grid

2. Stage 3, chopped modes

    a. calculate the pointing

    b. add BSM and pointing timelines to detector timeline

    c. demodulate detector signal

    d. second level deglitching

    e. average data per nod and jiggle position

    f. de-nod

    g. average all nod positions (*Level-1* product)

3. Stage 4, 7-point jiggle map

   a. derive source power

   b. combine pixels into single value (*Level-2* product)

4. Stage 4, small map

   • re-grid onto fixed sky grid (*Level-2* product)

7.2.3. Spectrometer pipeline

The FTS pipeline tasks

Procedure 7.3. Spectrometer stage 3 and 4 pipeline

1. Stage 3

   a. remove time domain phase

   b. drift removal (optional))

   c. interpolate to regularly sampled interferograms

   d. correct for vignetting as function of OPD

   e. correct for modulation efficiency

   f. correct for SCAL emission

   g. correct for telescope emission

   h. second level comparative deglitching

   i. average interferograms (optional)

2. Stage 4

   a. transform double-sided interferograms

   b. compute phase

   c. phase correction, low resolution

   d. phase correction, high resolution

      i. apodise

      ii. transform

   e. remove relative spectral response function

f.   change velocity frame (*level-1* product)

Chapter 8. Changes to the document

In this chapter we give the most important changes with respect to the previous versions of the manual.

8.1. Changes in version 1.2

- Updates in Chapter 4: *Observing with SPIRE*:

  - The description of the SPIRE Spectrometer AOTs for different spectral resolutions are explained in more details, especially the case for "High+Low" spectral resolution. A figure, showing schematically the SMEC scanning for the different spectral resolutions, is added.

  - Better explanations for cross-linked large maps.

  - Practical equations to transform chop avoidance angles to Herschel focal plane position angles, useful for checking with HSpot the visibility of observations with chop avoidance constraints.

  - Practical equations to transform map scan angle to Herschel focal plane position angle, useful for checking with HSpot the visibility of maps with map orientation constraints.

- Updates in Chapter 6: *Using HSpot to Create SPIRE Observations*:

  - Added links to zip files with AORs for the examples.

  - Added subsection on time estimation detailed messages (Section 6.5: Time estimation detailed messages).

  - Updated and greatly simplified the example for point source photometry with chop avoidance angles in Section 6.6.2: SPIRE Photometer Point Source With Chop Avoidance Angle.

  - Updated with a better and more detailed example the case for large map with map orientation angle constraint in Section 6.6.6: SPIRE Photometer large map with array constraints.

  - Updated Section 6.7.1: SPIRE Spectrometer Single Pointing Mode, Sparse Sampling illustrating some considerations with the spectral resolution when preparing SPIRE FTS observations.

- Corrections to text, mainly in Chapter 3: *General performance (scientific capabilities)*, Chapter 4: *Observing with SPIRE* and Chapter 6: *Using HSpot to Create SPIRE Observations*.

- Better figure placement in Chapter 4: *Observing with SPIRE*.

8.2. Changes in version 1.1

- Added Chapter 8 (this chapter).

- Updated Section 2.3.1.

- Updated Section 2.3.6.

- Updated Chapter 4, Chapter 3 and Chapter 6 to reflect the changes in the AOTs, the most significant of which are the user option of Scan Direction, which allows to make Large Maps with cross-linked maps, and the option to select the speed of the scanning of the telescope. A number of figures were added to better illustrate the large map mode, including coverage maps.

- Updated Figure 3.2 in Chapter 3.

- Some figures were unnecessarily big in Chapter 6. Resized.

- Screenshots in Chapter 6 were updated to show the latest SPIRE functionality with up to date numbers.

- Added example in Section 6.6.2.

- Updated the example in Section 6.7.3.

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